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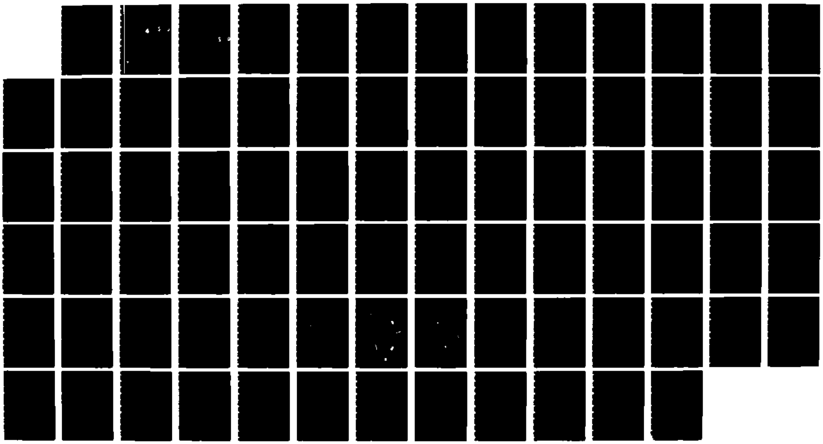

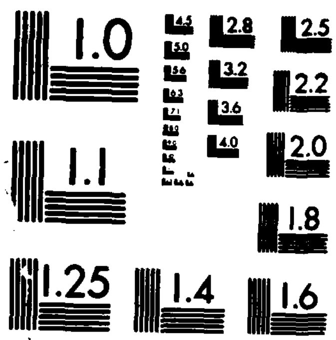

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Status Report on Ocean Data Telemetry

by

Melbourne G. Briscoe

July 1986

Technical Report

Funding was provided by the Office of Naval Research under contract Nos. N00014-84-C-0134, NR 083-400 and N00014-85-C-0001, NR 083-004.

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Approved for Distribution:

Robert C Beardsley

Robert C. Beardsley, Chairman
Department of Physical Oceanography

Abstract

This document contains two workshop reports and several brief technical reports, all on aspects of ocean data telemetry and platform positioning. The principal topic is a Summary of an Ocean Telemetry Workshop held at the AGU/ASLO Ocean Sciences Meeting in New Orleans, Louisiana, on 15 January 1986. A brief version of this summary appeared in **EOS, Transactions of the American Geophysical Union,** 4 March 1986. Both the full summary presented here and the brief form in **EOS** were coauthored by D. Brooks of Texas A&M University.

Included here is a list of the attendees at that workshop (**Appendix A**), and a description of the goals and membership of the AGU Ocean Sciences *Section Technical Committee on Ocean Data Telemetry and Platform Positioning,* which was formed at that meeting (**Appendix B**).

An earlier, informal, local workshop on telemetry was held at Woods Hole in March 1985; a report on that meeting is in **Appendix C**.

Technical summaries are given on Meteor-Burst Telemetry (**Appendix D**), the GEOSTAR positioning system (**Appendix E**), tradeoffs for various telemetry systems (**Appendix F**), a proposed communications network [authored by M. Comberiate from NASA Goddard] (**Appendix G**), and the possibilities of a new kind of HF telemetry system (**Appendix H**).

A small discussion at Woods Hole prior to the January Telemetry Workshop is reported in **Appendix I.**

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Executive Summary

This summary is the text of a Meeting Report that appeared in: **THE OCEANOGRAPHY REPORT, EOS** (4 March 1986).

OCEAN TELEMETRY WORKSHOP
AGU Ocean Sciences/ASLO meeting, New Orleans, LA, 15 January 1986

Conveners: Melbourne G. Briscoe and David A. Brooks

An informal workshop on ocean telemetry and platform location was held on 15 January 1986, during the ocean sciences meeting in New Orleans, LA. Plans for the workshop grew from a perception that present methods of data transmission and platform location may be inadequate for projected needs. The objectives of the workshop were to:

1. Identify present and promising methods of ocean telemetry and platform location,
2. Estimate needs for these capabilities during the next decade, and
3. Identify for focused development a few promising methods.

As a starting point, it was recognized that many experiments, but especially large ocean experiments with decadal time scales and global space scales, have much to gain from telemetry. The principal scientific advantages are quasi-real time data recovery, insurance against premature failures, adaptive control of instrument functions, expendability of instruments, and the potential for rapid data assimilation by models and distribution of data to users. Only in limited cases have these advantages even partially been exploited.

Participants in the workshop represented field and theoretical oceanography, numerical modeling, instrument development and engineering, and science-supporting agencies. After an opening series of brief talks that highlighted major issues, a discussion was held to try to identify a few proven or promising telemetry and platform-location methods that could be coherently and convincingly advanced by the ocean community. The results were by no means conclusive, but a consensus did emerge (in the conveners' opinions) that several methods should be vigorously pursued and that a few other concepts should be tested. The salient results and suggested actions are summarized here. A document giving a more detailed description of the workshop activities and results is forthcoming in the Woods Hole Oceanographic Institution Technical Report series. The committee referred to below is the newly-constituted AGU Ocean Sciences Committee on Telemetry and Platform Location.

I. Geosynchronous Satellites

It was noted that the ATS (Applications Technology Satellite) system has raised our awareness of and demand for modern data transmission methods. The ATS system is almost 20 years old, has far outlived its original mission, and has no successor; ATS-3 is presently in daily use, but it is not known how much longer reliable service may be expected. Commercial alternatives such as INMARSAT are available, but the high station cost ($50-100k) and need for stabilized antennas preclude extensive shipboard use at present. Efforts are presently underway to obtain ATS-like service from a new series of experimental satellites.

ACTION: The committee will encourage and support all efforts to gain access to new satellite systems.

The U.S. GOES satellites provide a medium data rate (about 10 bit/s averaged over a day) collection system that has widespread use in meteorology and that could be more extensively used with data-intensive ocean platforms. The GOES satellites basically are limited to the non-polar regions of the Atlantic and western Pacific, but similar systems operated by Japan and western European countries in principle could be used to expand the non-polar GOES-like coverage globally. To do so would require considerable international or interagency agreement and negotiation.

ACTION: A selected group or agency is needed to facilitate access to the international complex of GOES-like satellites, so that individual investigators will have to deal only with the interface group.

GEOSTAR is a new system of platform location that uses two geosynchronous satellites to interrogate a platform to determine its position. Coverage initially will be limited mainly to the U.S. and adjacent waters. A prototype system may be operational in late 1986. Expected platform cost is about $1200, with a monthly fee of about $50. Data rates of 256 bits/transmission (the same as ARGOS) will be accommodated. Positioning accuracy is expected to be 2-7 meters.

ACTION: GEOSTAR has promise and should be considered for oceanographic use when and if the system becomes demonstrably useful.

II. Polar Orbiters

ARGOS. Probably the satellite system most widely used in oceanography is ARGOS, which is a French doppler platform location system orbiting on several of the U.S. NOAA/TIROS satellites. ARGOS is a proven system that is relatively inexpensive and simple to use, largely because international and interagency agreements circumvent overwhelming paperwork. Generally, ARGOS provides only a very low data-rate for telemetry (256 bits per transmission, or about 0.1 bit/s averaged over a day, typically), and the next generation ARGOS system will have the same limitation on data transmission. The present version of ARGOS is limited to 200 platforms simultaneously in view, with a global maximum of 2500 platforms. In the next few years, the present system may become saturated in the North Atlantic, without considering the large

upcoming demands of WOCE and TOGA. ARGOS-2 depends upon the funding of a new series of satellites (NOAA K,L, and M); it should be able in 1991 to handle 5000 platforms with 855 in view at once. The ultimate ARGOS-2 capacity by 1995 could be 1710 platforms simultaneously in view with 10,000 platforms globally if the U.S. funds the Polar Platform satellite as well. Even with the expanded capacity, it appears that during WOCE the platform-location capability may be near saturation in some areas of the world ocean, especially the North Atlantic.

ACTION: ARGOS-2 design is frozen; lobby for the continuation of the NOAA satellite series that support ARGOS.

SATELLITES-OF-OPPORTUNITY. Many polar-orbiting satellites carry transponders, and under certain circumstances these can be used to relay data from remote stations to more elaborate ground stations that are in view of the GOES satellites. In some cases, these transponders may be available for medium to high rate ocean data relay from regions not directly covered by the GOES system. Such a system has been developed by NASA, with cooperation from the NSF and NOAA, for Antarctic ground communication. Ranges of at least 1000 km between the remote and the relaying ground stations are practical. With a few strategically located ground stations, coverage of both polar oceans could be greatly enhanced. An opportunity exists to place a suitable transponder on the COBE (Cosmic Background Explorer) satellite, which is scheduled to be launched in 1988; ocean community support is needed now for this "satellite-of-opportunity" project.

ACTION: The committee will encourage NASA/NSF/NOAA cooperative agreements to use polar-orbiter transponders to fill in data-access gaps.

III. Alternative Possibilities

METEOR-SCATTER (OR METEOR-BURST) COMMUNICATION utilizes ionized meteor trails to provide sporadic propagation paths between a master station and a number of slave stations. A two-way acknowledgment protocol is used, and data rates of about 50-100 bit/s on average can be accomplished over station separations of 2000 km or less. Limited testing has shown the method to be potentially useful for data telemetry from ocean buoys, provided a small number of master stations can be located around ocean basins. A master station costs $75-100k and a slave station (i.e. for a drifter or mooring) costs $5-10k in small numbers. There are diurnal and seasonal cycles of meteors, but coverage is claimed to be essentially year-round and global except for some sporadic polar cap absorption events.

ACTION: Meteor-scatter has a definite but not well tested potential for two-way communication at medium rates with drifting or moored instruments. A few more proof-of-concept experiments using stations on a ship and a drifter should be carried out.

HF PACKET RADIO also uses a two-way, error-checking protocol over HF (high frequency) channels, which require ionospheric refraction for communication. The traditional shortcomings of changing propagation conditions are mostly overcome by sending small "packets" of information to many receivers in various locations (diversity reception). Data rates are 300-1200 bit/s with the throughput being less due to the handshaking. In the last few years, packet technology has become highly developed and inexpensive, mostly due to amateur radio applications, and this technology readily can be applied to ocean telemetry needs. The next sunspot cycle peaks near 1992, and HF propagation conditions should be at their best in a 5-6 year window centered on that time. There are presently several HF frequency bands assigned for ocean usage, but these evidently are in danger of being lost unless an active interest in their use is expressed soon.

ACTION: The committee will take immediate steps to preserve the presently-assigned HF bands. Once lost, they will be essentially irretrievable. Packet radio telemetry techniques should be considered seriously if results from a test to be conducted in the fall of 1986 are favorable.

CONCLUDING REMARKS

Several satellite systems jointly appear to have the potential to meet most of the platform positioning requirements for the next decade, but there is concern that the ARGOS system, even when updated, will be overloaded. Higher data-rate satellite systems presently are limited to the non-polar Atlantic and eastern Pacific (U.S. GOES); wider commercial coverage is available but prohibitively expensive or mechanically impractical. International access to other countries' GOES-like facilities could alleviate the problem in non-polar oceans, but a practical method to deal with the complex arrangements is needed. Polar coverage may be improved by using GOES-linked ground stations to relay data from transponders on polar orbiters. In any event, prudence dictates that one or more alternative methods of telemetry, such as meteor-scatter or HF packet, should be exploited to provide a backup for satellite systems in case they fail to become available for any reason, to provide a non-satellite based telemetry system under the control of the oceanographic community, and to provide a higher data-rate channel than otherwise available.

From the present perspective, it appears that no single system will adequately meet the needs for data telemetry and platform location in the next decade. A mixture of a few different techniques, mainly based on polar-orbiting and synchronous satellites, but complemented by ionospheric schemes for backup and gap-filling, seems to offer the best prospect for flexible and reliable service to the ocean community.

SUMMARY OF AN OCEAN TELEMETRY WORKSHOP HELD AT THE AGU/ASLO OCEAN SCIENCES MEETING IN NEW ORLEANS, 15 JANUARY 1986

by

Melbourne G. Briscoe, Woods Hole Oceanographic Institution
David A. Brooks, Texas A&M University

INTRODUCTION

Telemetry of data from ocean platforms to shore is not a new idea, but the growing interest in expendable instrumentation, long-term moorings, large numbers of drifters, and projects requiring sophisticated data networks has prompted a reexamination of where we are and where we are going.

Robert Heinmiller of Omnet, long a proponent of telemetering one's data, Worth Nowlin of Texas A&M, and the authors were part of several informal meetings and discussions during 1985 about the future of ocean data telemetry. These talks motivated the workshop reported upon here; it seemed that early 1986 would be a good time to get some discussion going in order to meet various planning and proposing deadlines for 1986. Of the several possible meetings already planned during the first half of 1986, the AGU/ASLO Ocean Sciences meeting was the first choice because it was the earliest, it was likely to have the greatest concentration of oceanographers, and under the AGU it was possible expeditiously to form technical committees to follow up any leads and action items that might result from the meeting.

An informal planning committee composed of Bob Heinmiller, Dave Brooks, Mel Briscoe, Bob Chase, John Masterson, Worth Nowlin, and Dale Pillsbury, with input from Gene Silva, Tom Curtin, and Larry Clark (see Appendix for names, addresses, and affiliations) prepared a rough agenda and worked with Bob Willems, co-chairman of the Ocean Sciences Meeting, to get a half-day workshop arranged and advertised on Telemail, in EOS, and by a mailing sent out by Nowlin from the US-WOCE Project Office at Texas A&M University. Telemail was, in fact, the principal means of planning and coordinating the workshop: the files of one of us (MGB) contain some 113 Telemail messages between 28 October and 10 January, all directly related to the workshop. We were all very impressed with the use of electronic mail coupled with multi-person addressing capability to permit a complex issue to be discussed and resolved with no meetings and surprisingly little effort.

The actual meeting was organized around a series of short, informal presentations arranged ahead of time by Brooks and Briscoe, who acted as moderators of the session that ran from 2:00 p.m. to 5:20 p.m. on 15 January. General discussion of the informal presentations was encouraged, which led to complementary discussions. After a break, a completely informal comments session was led that provided short contributions on a number of topics.

A telephone call was made to one prearranged contributor (Mike Comberiate) who was unable to attend. The call was amplified for the entire workshop room to hear and ask questions; his slides were shown by an attending colleague. As with Telemail as a planning medium, we were impressed with this use of simple telephone and amplification equipment to allow a useful presentation and two-way exchange to be held *in absentia*.

The afternoon workshop was concluded with the informal presentation of a list of items that had been discussed on which there was apparent agreement as to their importance and the worth of following them up. To initiate some follow-up action, and to get a second reading on whether the list of important items and conclusions was reasonably correct, thirteen of the attendees met for breakfast the following morning, 16 January, from 7:00 a.m. to 8:30 a.m. The breakfast was sponsored by the AGU as an aid to the formation of an Ocean Data Telemetry Technical Committee under the Ocean Sciences Section. Those attending the working breakfast were Briscoe, Brooks, Clark, Curtin, Flanders, Muench, Rossby, Evans, O. Brown, W. Brown, McClain, Van Leer, and Softley. The total attendance at the breakfast was necessarily limited; this particular group was chosen to represent a cross-section of academic, agency, commercial, and scientific and technical interests. The actual AGU technical committee still remained to be formed.

In the following sections, the topics discussed and the conclusions relative to them are grouped by similar topics; this presentation does not follow the actual chronological activities of the workshop, and combines the discussions of the open afternoon workshop with those of the morning breakfast the next day. Where possible, the source of the particular fact or idea or comment is given in parentheses. All the conclusions and recommendations are summarized at the end of this report and a sense of their relative importance and priority is given there.

M. Briscoe and D. Brooks are solely responsible for the contents of this report, which we hope accurately reflects the discussions at the workshop, and we thank all those who contributed to its formation and success. We learned a lot, and we anticipate that this report will help those who were unable to attend to acquire a reasonable fraction of the very interesting and helpful information that was exchanged.

WHY TELEMETRY?

The original reason to telemeter oceanic data was because of an inability to record the data *in situ*; now, the quantity of data that is measurable at an instrument can demand some kind of remote recording of the data. A doppler acoustic profiler, even if the data are averaged over 2 minutes, can easily produce some 100 bit/second; this is some 10 million bits per day, enough to fill an entire Sea Data cassette, for example. Even the newest recording media can only record a few days at this rate. The solutions are to reduce the data *in situ*, which often requires more knowledge of the environment than is available, or to telemeter the data.

The most common reason today for data telemetry seems to be a need for the data in near-real time, which means different things to different people. The need may arise from the desire to use the data to make decisions about the experiment, or to permit an ongoing analysis of the data, or to be able to distribute the data quickly. The most interesting new application of near-real time data is for assimilative and predictive models that require ongoing data input to keep them updated.

As equipment is put into more difficult situations, like high current regimes or heavy weather conditions, there is a need for constant or sporadic performance monitoring to reduce the risk of the situation. Knowledge that the instruments are working improperly may allow the investigator to correct the situation and possibly save the experiment.

Two-way telemetry also allows the control of a remote instrument, which may permit adaptive experimentation using human intelligence ashore rather than minimal electronic intelligence in the instrument.

The potentially largest category of telemetry use, however, involves expendable instrumentation such as surface or subsurface drifters. The present generation of these drifters uses Service ARGOS (see below) for location of the drifter and for passing a small amount of data, for example surface temperature. Although most of the surface drifters require very low data rates, perhaps just 256 bits a day, other drifters like the RELAYS buoy (E. Mellinger) or the drifting doppler profiler (L. Gordon) can easily demand 100 bit/second or more.

In summary, the principal motivations for ocean data telemetry are:

- reduce risks
- adaptive experimentation
- performance monitoring
- control of instruments
- expendable instrumentation
- remote recording
- rapid data distribution

It is likely that the expendable instrumentation category will be the largest user of telemetry, but that the remote recording category will be the most demanding (because of the potentially high data rates).

STATUS REPORT: ATS, ARGOS, GOES, and INMARSAT

ATS (E. Mellinger, O. Brown)

The Applications Technology Satellite series was a test program by NASA that began in the 1960's. ATS-3 was launched in 1967 as a test of direct broadcast of television to remote locations. In the early 1970's the satellite was made available to the oceanography community for communications from research ships; in the late 1970's the entire satellite and its handling

system were turned over to a facility run for the oceanographic community by Paul Eden under contract from the NSF.

Presently available are 5 voice channels, of which only 3 are really usable, and several bands for data telemetry at 1200 baud nominal rates, although 4800 baud might be possible with some of the new modems available. ATS-3 is in geosynchronous orbit with 24 hour coverage from (approximately) Hawaii to the Azores, and to about 70 degrees latitude; the orbital inclination allows the poles to be seen for about 4 hours each day.

ATS-1 has a similar capability but is presently unused as it slowly drifts eastward; it is now at about 70 degrees west and may be reactivated later to give coverage of the eastern Atlantic and even into parts of the Indian Ocean.

ATS-3 was only designed to last 18 months and is now nearing its 20th birthday; it is all solid state with solar power and batteries for temporary backup, and it is working well. It may last for a very long time or fail without warning.

The uplink is near 149 MHz and the downlink is near 136 MHz, so only simple equipment is needed, although the antenna must be stably trained to point at the satellite and is typically a multi-element crossed yagi. Experiments have been run with very simple omnidirectional antennas of the kind that would be reasonable on a small buoy, but no use is presently being made of this capability.

The two-way communication possibility through ATS-3 allows the desirable control of a remote system as well as a hand-shaking telemetry protocol. A new version of the ATS Users Manual is available from the NSF (L. Clark). Typical use of the ATS is for voice communications from oceanographic research ships to their home laboratories and with each other, plus a small amount of data transmission, for example Telemail and facsimile of satellite IR representations. The present schedule has three one-hour time slots a day for the oceanographic voice traffic, with 24-hour availability of the data channels.

The many years of experience of the oceanographic community with ATS has shown the value and necessity of such a communications system; although commercial systems like INMARSAT can be partial replacements for ATS, the installation and operating cost of INMARSAT (see below) is a severe hindrance to its wide acceptance.

ARGOS (A. Shaw)

The ARGOS system is a French instrument aboard a NOAA satellite (the TIROS or NOAA series), and a combination of U.S. and French ground stations plus a French computing system. Operational since 1979, ARGOS has proven itself during FGGE and in numerous smaller experiments, and is planned for use during TOGA and WOCE.

The data downlinked from ARGOS is received at one of three ground stations, sent to France, processed, and then made available over systems like GTS (the Global Telecommunications System for meteorological data) or Tymnet; the delay is always a few hours to get one's data through this scheme, and sometimes much longer if there is a hangup somewhere. In addition, data tapes or printouts can be received monthly or biweekly.

More immediate access to the ARGOS data can be had with a Local Users Terminal (LUT) that receives the direct downlink that is essentially simultaneous with the uplink. The limitation is that both the platform and the LUT must be in the satellite footprint, and of course the user has then to do all his own data processing, including the algorithms for platform positioning. The LUT depends completely upon the downlink at 136.7 or 137.7 MHz, two frequencies that may be lost to such use if NASA agrees to release them by 1990 as they have previously tentatively agreed to do. A major task of the Ocean Data Telemetry Technical Committee mentioned in the INTRODUCTION will be to make every attempt to keep these frequencies for oceanographic use.

> **NOTE:** On 11 March 1986 the NOAA NESDIS Specification Change Control Panel directed its contractor to do an accommodation study concerning retention of the VHF downlink capability on the NOAA-K and beyond satellites. This action came partly as a result of the input from users and potential users of LUTs. The AGU Ocean Sciences Section Telemetry Committee was instrumental in making these users aware of the impending decision and suggested they write the Panel with their views.

The great advantage of ARGOS is its ability to determine the geographical position of an object, which it does by processing the doppler shift in the signal transmitted by the platform, for example a drifting buoy. The uplink, typically a few millisecond burst at 401.65 MHz at a one-minute repetition rate, carries a maximum message length of 256 bits. Although 256 bits every minute is an average of 4 bit/second, the polar-orbiting satellite is in view for only a few minutes every few hours, depending on one's latitude. Typically, 8 transmissions every 2 hours are possible, which is about 0.3 bit/second on average over a day. However, to insure that the data transmissions are received without error, the transmissions are usually repeated several times for redundancy. The typical data throughput with ARGOS is therefore about 0.1 bit/second, or fewer than 1000 (ten-bit) characters per day.

The present version of ARGOS is limited to 200 platforms in the field of view (about 5000 km diameter) and 2500 platforms worldwide. Fewer than 1000 platforms are in use at the present time, but the concentration of them in the northwestern European area (due to North Sea operations) has 85-percent saturated the system there. Planned work in the Greenland-Iceland-Norwegian Sea area in the next few years will likely cause saturation. ARGOS predicts 3000 platforms worldwide by 1990, 5000 by 1995, and 10,000 by the year 2000. They have designed ARGOS-2 to be available in 1990 with the capability for

5000 platforms total and 855 in a footprint, with an additional upgrade in 1995 to twice that capability. However, discussion by workshop participants points out that the ARGOS capability may be insufficient by 1990, even if ARGOS-2 becomes a reality, and that even the enhanced ARGOS-2 in 1996 may be insufficient. And this assumes, of course, that the U.S. will fly the NOAA K,L, and M series that ARGOS-2 requires.

In a discussion of the uses and potential saturation of ARGOS, the point was repeatedly made that the great advantage of ARGOS was its positioning ability, and that its data handling skill was quite low. It was felt that the use of ARGOS should be reserved for those projects actually requiring positioning and not be inefficiently utilized by data transmitters. This may help, but it would be conservative also to investigate alternative platform positioning schemes, which include LORAN retransmission, GEOSTAR (see below), and potentially smaller and cheaper GPS receivers. The concept is to use, say, a LORAN receiver on a buoy and to transmit its output along with the data stream. Such systems have been tested and are commercially available, but are not yet at the low cost level of the ARGOS system.

One inherent advantage of the ARGOS system is its ease of use; through the governmental agreements signed and the U.S. picking up a part of the data handling charges, an individual investigator can gain ready access to the system and can obtain his data at low cost.

GOES (O. Brown, R. Evans)

There is a Data Collection System (DCS) on the GOES geostationary satellites that is capable of handling considerable higher data rates than ARGOS. There is no positioning scheme but if position were determined separately then it could be included in the data stream. The maximum data throughput is 100 bit/s, but data must only be sent at prearranged times; permission is obtained from NOAA, who assigns a time interval of a minute every 3 hours or so for data transmission. This suggests effective throughputs of order 1 bit/s.

Modest antennas and power level are sufficient on the platform, so the principal limitation is the lack of a positioning system. However, the two GOES satellites only cover the Atlantic and the eastern Pacific, with no real polar coverage. The GMS satellite from Japan is similar and covers the western Pacific, INSAT-1D covers the Indian Ocean, and METEOSAT from western Europe covers the eastern Atlantic and the western Indian Ocean. If one were to arrange access to all these satellites, and could arrange a way to get the data home from each of the national agencies running them, one would have decent non-polar coverage of the globe with a moderate data-rate system.

A strong recommendation from the workshop was to investigate ways that some group or agency could act as an interface for the use of the international complex of GOES-like satellites, so that only the interface group would have to arrange the necessary accesses and data distribution network. Individual U.S. investigators could then simply deal with the interface group. The idea has merit in several of the applications discussed

here, but is especially relevant in those situations requiring considerable international or interagency agreement and negotiation.

Little oceanographic use is made of GOES, apparently because it does not provide the desirable positioning capability. But if the GOES data rates are required, then an ARGOS positioning transmitter could always be an add-on, or in some locations LORAN or another scheme could be added and retransmitted.

INMARSAT

Originally called MARISAT, this communications system is now international and run by the COMSAT corporation. It is based on an array of geostationary satellites that provide worldwide coverage except at the poles. Even though 56 kbaud data throughputs are available, there are two principal disadvantages to the oceanographic community: first, it is some $50k to capitalize the station, which requires large gyro-stabilized antennas, and secondly, the minimum user cost is about $10/minute (voice or low data rates) and much higher for the high data rates. For some oceanographic ships INMARSAT may replace or supplement ATS, but in general it does not suit a major need except for seismic operations that must send the entire data stream back home for analysis.

The missing ease of use of the GOES system described above, due to the multinational, multiagency arrangements that must be made, are taken care of with the INMARSAT system via the auspices of COMSAT and the INMARSAT consortium itself; the biggest advantage of INMARSAT to the oceanographic community may be the model it presents about how to get data back from a complex of GOES-like satellites.

OTHER POSSIBLE SYSTEMS: METEOR-BURST, GEOSTAR, and HF PACKET

METEOR-BURST (A. Flanders, M. Briscoe)
(see also Appendix D)

Meteor-burst uses scatter of 40-50 MHz signals from the ionized trails left by sand-grain sized meteors striking our upper atmosphere. The scheme is 50 years old but has not been much used because many of its advantages were not realizable until the advent of microprocessors and cheap memory.

A master station ashore sends out a beacon that is sporadically heard by a remote station whenever a meteor trail permits the beacon signal to be scattered to the remote. The remote sends a 10 kbaud data burst for a fraction of a second, which is acknowledged as having been received intact by the master (using some scheme like a cyclic redundancy check). The pattern of send. check, and acknowledge is repeated until the meteor trail dies away, which may take a few seconds at most. Although the number of meteors striking the atmosphere has a diurnal and a seasonal cycle, between two points separated not more than 2000 km data throughputs of 50-100 bit/second on average are typical.

The system is expensive by most oceanographic standards, about $75-100k for the master and $5-10k for the remote (like the cost a few years ago for ARGOS transmitters!), but there has been no quantity market for meteor-burst and nothing to drive the costs down. Antenna needs are substantial at the master but minimal at the remote.

No real oceanographic use of meteor-burst has been made, but two tests have been run. In one, an oil tanker in the Gulf of Alaska was tracked by using meteor-burst to retransmit a LORAN receiver aboard. In the other, a simple buoy in a pond acted as the remote in a test of the antenna performance. Both tests indicated the potential usefulness of the concept.

An application for meteor-burst might be from a research ship that has a doppler acoustic profiler aboard; neither ARGOS nor GOES could handle the data rate from the profiler, and INMARSAT would be prohibitively expensive to operate except for an occasional data-dump through the high data-rate channel. But meteor-burst could handle the 2-minute averaged profiler data with only minor delays to wait for the next scattering path.

It was the sense of the workshop that meteor-burst had definite, although restricted, applications in oceanography, and that we should try to obtain additional information on the performance of a remote aboard a ship and aboard a large and a small buoy. It was noted that only a few master stations were required to cover the entire western North Atlantic.

GEOSTAR (M. Briscoe, E. Mellinger, R. Evans)
(see also Appendix E)

The ARGOS positioning is done by calculating the doppler shift in the precision carrier frequency transmitted by the platform. This is an upside-down version of the positioning method used in the TRANSIT or GPS satellites. GEOSTAR, on the other hand, is a transponder system in which two geostationary satellites interrogate the platform, which transponds back to the satellites. A ground computer uplinks the interrogation command, receives the transponder response, and calculates the platform position. GEOSTAR has received FCC approval for the scheme and hopes to start up its prototype system in late 1986. They have estimated 2-7 meters location accuracy. Since each platform is a transponder, two-way communications are possible, but the uplinked data from the platform is only 256 bits maximum with each transmission. In principal, a large number of transmissions would permit a large number of bits to be put through the system, but costs will probably prevent this. The expected platform cost is about $1200, there is a maintenance fee of some $40-50 per month per platform, and a cost for each location or data transmission that may be of order one dollar.

The overriding limitation of GEOSTAR is its coverage of mainly the continental United States. More geostationary satellites and a more complicated computer system would be required to have worldwide (but non-polar) coverage. Even so, GEOSTAR may provide useful coverage of the western North Atlantic and the eastern North Pacific, and more data and better

locations than ARGOS provides. Even if all GEOSTAR does is take the load off ARGOS for some oceanic regions, it could be quite helpful.

It was the sense of the workshop that GEOSTAR should be watched closely and evaluated for oceanographic use when ready, which probably means some at-sea testing and intercomparison with ARGOS and other schemes.

HF PACKET (M. Briscoe)

(see also Appendix H)

Twenty years ago high-frequency (HF) radio, commonly called short wave radio, was pushed aside in favor of various satellite telemetry methods. The main disadvantages of HF are the somewhat predictable but always changing propagation and skip characteristics, and its susceptibility to noise and interference. Signals could be transmitted, but often they would not get where they were going, and when they did they were often full of errors.

The packet-switching networks used on Telenet, for example, use a sending protocol that adds error-checking characters to each group of message characters transmitted. If the receiving point checks and thinks it has received the message correctly, it acknowledges its receipt, which is the go-ahead for the originator to send the next packet of information. This kind of half-duplex send-and-acknowledge system is not as efficient as some other possibilities, but it works well and is in common use.

Amateur radio operators have recently modified the X.25 protocol described above to permit its use over radio; the modification (AX.25) is the addition to each packet of a header that contains destination and routing information so all those stations that hear the transmitted packet know which of them is supposed to deal with it, and how. The equipment to perform all the formatting, checking, and acknowledging costs under $200; a radio plugs into one end of the interface and a terminal or computer plugs into the RS232 port on the other end. The system is used on the ham bands at 300 baud with AFSK modulation, and could go faster but for the restrictions by the FCC on what is permissible in the ham bands.

Called packet radio by the hams, this is the obvious way to eliminate the uncertainty traditionally associated with telemetry by HF radio. The added complication on the platform is the packet board and a receiver.

Technological developments in the last twenty years have not changed the fundamental problems of HF propagation, but many of the problems can be avoided by the simple observation that even though the signal does not propagate where you want it to, it does propagate somewhere. The trick then, is "diversity reception," i.e., lots of receiving stations in all kinds of locations, both near and far from the platform, and east and west of it, and north and south of it. When the platform is ready to transmit some data, it attempts to connect with one of the receiving stations. When it finds one, it begins the send-and-acknowledge packet scheme, and continues until either it has dumped its data or lost the path. HF packet is perfectly feasible even for just one platform and one receiving station, but diversity reception is

probably inefficient unless there are many platforms to have their data shared into the receiving net.

HF packet with diversity reception has not been attempted from a platform at sea, but there may be an attempt this fall to prove the concept using amateur radio equipment and operators. If successful, the translation to commercial equipment on allocated frequencies (and using more powerful modulation schemes) could greatly enhance the possibilities.

The advantage of HF packet relative to other telemetry possibilities is its avoidance of sometimes doubtful satellite links and the nearly complete avoidance of national and agency negotiations. ARGOS has been popular because it requires a minimum of paperwork to use. HF packet, except for the initial licensing, requires none. Also, it is latitude and geographically independent. In these respects, that is independence and transportability, meteor-burst and HF packet are similar: neither uses satellites and neither requires special agreements. However, both may require a careful placement of shore stations and both may require a prearrangement to get the data home from the receiving station.

MISCELLANEOUS: POLAR COMMUNICATIONS, and IN-WATER LINKS

POLAR COMMUNICATIONS

See Appendix G for an extended explanation of this concept.

IN-WATER LINKS (E. Mellinger, E. Softley)

Even with a perfect method to get the data from the surface to home. there is still often a need to acoustically transmit the data through the water column to the surface. The vertical propagation problem is the simplest except for the interference caused by surface reflections, and has been solved by several people in somewhat different ways. There has been slow-scan TV sent vertically at 2400 baud, and 300 baud is acknowledged to be fairly straightforward over distances of a kilometer or so. There is unpublished and classified work in this area, and although the commercial and Navy sectors feel the problem is no longer a technical problem, the academic sector is not convinced that workable equipment actually exists or that it is obtainable at reasonable cost.

The horizontal propagation problem. as for example in getting data out from under ice or under the Gulf Stream to a quieter location, is more difficult because of the refraction due to the variable sound speed profile. In some conditions, at short ranges (less than a few kilometers) horizontal telemetry at 50-300 baud has been done, but at any ranges greater than perhaps 10 km the rates drop to a few baud. There are stories of equipment to do the job, but at $100k plus prices. Clearly, optical fiber and electromagnetic links are possible and are in use to move data around underwater. For modest distances the mechanical problems are not insurmountable.

Although the workshop showed interest in the in-water telemetry links, it was not an area of expertise for many in the audience. At the next such workshop the in-water link, especially acoustics, should be part of the formal agenda and an effort made to have the appropriate people present. It is the impression of the authors that the limiting factor in the overall link from a subsurface instrument to home is not presently the in-water portion; data rates achievable underwater, even acoustically, seem larger than ARGOS provides, for example. We suggest that a survey of what has been done with acoustic telemetry and what equipment is available would be very useful, since such information was not part of this workshop.

FUTURE NEEDS

The estimates of ARGOS capability versus various estimates of future needs were discussed earlier. This topic needs to be addressed carefully and periodically. The last two published estimates of which we are aware are from a 1982 NASA working group report chaired by Russ Davis, and from a Status Report on US-WOCE planning, which considers only drifters for WOCE and not other needs.

At the workshop, we heard the following statements of need for ocean data telemetry:

- in the Gulf Stream region there are planned to be 100 ARGOS drifters in 1987-88 and 50 in the South Pacific in 1986 (T. Rossby);
- numerical modelers would like to see a telemetering current meter array in the Gulf Stream region, with perhaps 40-50 moorings (E. Carter);
- MIZEX has a need for 40-50 buoys in the Fram Strait in 1989, with location of them necessary but more data desired for transmission than ARGOS permits (A. Baggeroer, by proxy);
- MIZEX and other profiling experiments are planning ten or more profiling stations, each needing to send 1-2000 data points (not bits) per hour, which is perhaps 5 bit/second on average (J. VanLeer);
- ships of opportunity might constitute 100 platforms each sending daily meteorological and XBT information, and some of these might have doppler profilers (C. Mooers);
- the WOCE estimate of 4000 drifters in the next decade might actually be more like 10000 (T. Rossby).

The clear feeling of the workshop was that a serious estimate of telemetry needs was required, and that it had to include data rate as well as just number of platforms: when will we saturate ARGOS, and what alternate higher-data rate schemes are needed?

CONCLUSIONS AND RECOMMENDATIONS

Telemetry of data from platforms at sea is a real need for many reasons; the most compelling are for expendable instrumentation and in those situations where the data cannot be recorded *in situ*. However, the growing need for near-real time data to permit adaptive experimentation and for input to assimilative models is providing an additional urgency to the problem.

The most popular oceanographic data links are ARGOS, ATS, and GOES. There is a real concern that ARGOS will be insufficient for our needs before the next ten years are over, even in its most expanded form that is contemplated; ARGOS is of special interest for its ability to locate a platform. ATS may fail at any day with replacements only being discussed. GOES does not have worldwide coverage, although with a major effort one might gain access to its counterparts for other oceans.

There are HF and VHF frequencies allocated to ocean data transmission that are on the verge of being lost, and there are high data-rate telemetry needs that are not being addressed at all. New satellites and schemes to use old ones have been mentioned, but the oceanographic community is rarely if at all part of the discussions.

Our principal conclusions are that ocean data telemetry is underutilized, and that as it becomes available we will see a corresponding increase in data return from high-risk experiments, a better distribution of data to cooperating investigators, and the availability of data from places and environmental situations that heretofore have been unexplored.

But there is work to do to accomplish this. We have taken three positive steps to begin the necessary work:

1) this workshop, and this report

2) a TELEMETRY bulletin board on Telemail's SCIENCEnet

3) formation of an AGU Ocean Sciences Section Technical Committee on Ocean Data Telemetry and Platform Positioning (see Appendix C)

We anticipate that distribution of this report will focus attention on the general problem and give those wishing to initiate some programs a bit more ammunition to work with.

We anticipate that the TELEMETRY board will act as a quick-response communication medium, especially for queries about who has done what and for information on various topics.

And finally, we expect that the AGU Technical Committee will be able to take some actions that will help protect some of our frequency allocations, and will be able to provide advice to researchers and funding agencies about the status of systems, need for enhancement in various areas, and in general as a focal point for the subject in the community.

ACTION ITEMS

1. Via the AGU Technical Committee on Ocean Data Telemetry, provide the additional information needed to help protect the presently available frequencies for ocean telemetry, especially the 6 HF bands and 2 VHF frequencies that are in danger of being lost.

2. Assess telemetry needs for the next 5 and the next 10 years, with especial attention to those needs requiring location, or high data rates, or at high latitudes.

3. Determine the tradeoffs between the various available systems for the various classes of needs.

4. Evaluate the potential of meteor-burst, HF packet, and GEOSTAR.

5. Investigate alternate satellites.

6. Determine a mechanism for simple access to the entire complex of GOES-like satellites and the DCS data from them.

7. Consider a follow-on workshop.

The Technical Committee, *D. Brooks and M. Briscoe, co-chairmen*, would be pleased to discuss any of these topics, or others, with anyone wishing to make some efforts toward the increased availability and capability of ocean data telemetry.

Acknowledgments

We acknowledge the continuing efforts of Bob Heinmiller of Omnet, and of Tom Curtin of ONR, in pushing the concept of ocean data telemetry. We hope that the AGU Technical Committee (see Appendix B) will be able to continue this task.

In the past, the efforts that we anticipate the Technical Committee will undertake have been performed in an *ad hoc* way by a small group of dedicated people, many of whom live in the Miami area. We have several excellent telemetry systems today due to their efforts, and the workshop and these authors owe them our gratitude.

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APPENDIX B: AGU OCEAN SCIENCES SECTION TECHNICAL COMMITTEE ON OCEAN DATA TELEMETRY AND PLATFORM POSITIONING

At the AGU/ASLO Ocean Sciences Meeting in New Orleans in January 1986, a section Technical Committee was proposed on 14 January to the section President-elect, Arnold Gordon of Lamont-Doherty Geological Observatory of Columbia University, by M.G. Briscoe of the Woods Hole Oceanographic Institution and D.A. Brooks of the Texas A&M University, who offered to act as co-chairmen of the Committee.

The proposal contained the following elements:

Purpose: "To examine and provide guidance to the oceanographic community on the needs for, status of, and possible directions for data communications with oceanographic platforms at sea."

Methods: "Formal and informal meetings and discussions, in a variety of forums and locations, with input from a cross-section of the telemetry and the oceanographic communities."

Reporting: "Timely and immediate communication by electronic mail via a TELEMETRY Bulletin Board on the SCIENCEnet system on Telemail, with reports in EOS and formal technical reports as appropriate."

Membership: "Not to exceed 12, and drawn broadly from the working oceanographic community, with representation from other societies where possible, especially the AMS and the MTS."

Topics: "Initial topics that would be addressed would include:

- maintaining the frequencies now allocated to ocean data telemetry, especially those in the HF band that are currently under review;
- preparation of a technical document summarizing the present and future telemetry systems that are, and are expected to be, available to the oceanographic community, including the means of access to these systems and their tradeoffs;
- increasing the awareness in the working oceanographic community and in the ocean funding-community of the usefulness of telemetry and of its availability;
- how to prepare and make recommendations as to useful directions for researchers and funders to pursue."

The first meeting of the potential Technical Committee and guests was held on the morning of 16 January. The current membership of the Committee is:

M. Briscoe and **R. Chase** (Woods Hole Oceanographic Institution); **D. Brooks** (Texas A&M Univ.); **R. Evans** and **O. Brown** (Univ. of Miami); **R. Muench** (Science Applications Inc., Seattle); **J. Irish** (Univ. of New Hampshire); **D. Pillsbury** (Oregon State Univ.); and **C. Koblinsky** (NASA Goddard).

APPENDIX C: INFORMAL MARCH 1985 TELEMETRY MEETING AT WOODS HOLE

TELEMETRY DISCUSSION
11 March 1985

Notes by Melbourne G. Briscoe

25 March 1985

As a way of bringing people up to date on past and present oceanographic programs that use RF or acoustic telemetry, especially from moorings, and to provide a forum for the discussion of new ideas and directions that might have common interest, a discussion meeting was held at WHOI on 11 March at noon, hosted by the weekly Buoy Luncheon.

The attendance at the discussion was primarily from the immediate Woods Hole community with a few people coming in from the Boston area. The meeting was extensively advertised locally and was announced on the WOCE.STATUS calendar on Telemail's SCIENCEnet. 44 people signed the attendance roster.

This is an outline-form summary report of the meeting, based on notes made by Bob Weller and George Tupper; some additional information is also included based on material provided by Bob Heinmiller and Doug Webb. An incomplete reference list is appended.

Motivations for Telemetry (order not meaningful)

1. Reduce costs (e.g., expendable moorings...no recovery ship needed)
2. Reduce risk (get some data back from difficult locations)
3. Obtain data before mooring recovery
4. Near real-time data needed (version of 3 above)
5. Redundancy (like 2 above)
6. Performance assessment (engineering information)
7. Increase data capacity (too much to store *in situ*)
8. Attention span of the investigator (subset of 3 above)
9. Getting data from "hostile areas" like Gulf Stream or under ice (related to 2 and 5 above)
10. Get data from the sensor to a recorder (remote recording, not remote sensing) (related to 7 above)
11. Permit adaptive experimentation (subset of 3 or 4 above)
12. Eliminate *in situ* recorders (related to 1, 7, 10 above)
13. Operational monitoring (e.g., currents in harbor entrances) (subset of 4 above)
14. On-line data distribution (e.g., meteorological data over GOES)
15. Control (telemetry to the mooring to effect some action)

Summary. The principal motivations, in priority order, are:

1. Get data during the experiment
2. Reduced risks
3. Remote recording
4. Reduced costs
5. Control

Historical Telemetering Activity (also, see References)

1. Early 20th century: underwater bell and radio signal to give the distance from lighthouses
2. 1940's: radiosondes (in meteorology)
3. 1940's, 50's: Roberts current meter (motivated by lack of *in situ* recording possibility)
4. 1953: Walden drift buoy with telemetering thermistor chain, located by triangulation from shore (Stommel and Walden, 1954)
5. The SOFAR channel as acoustic telemetry path dates from the early 1940's. Its use for drifting and telemetering floats dates from 1975.

Summary. RF and acoustic telemetry is a 30-50 year old activity, with much of the initial work being driven by an inability to reliably record data *in situ* as well as a desire to obtain the data in real time. Recent RF work has concentrated on high data-rate applications via satellite; HF telemetry is not common. Acoustic telemetry is concentrating on noisy and reverberant channels, with some attention to high data-rate transmissions over short and moderate distances, especially vertically.

Current Projects

1. ORE, in the North Sea, is using a digital acoustic data link to talk between a production platform and wellheads. Using 5 bit/s at 8-10 kHz over a 10 km range in 100 m of water, the two-way paths have been about 90% reliable over a 6 month period. Pressure and temperature are being telemetered in response to a command from the platform. About 1 kW peak power is being put into the transducers, and the battery life at the wellheads is about 6-12 months. The main problems are power and reverberation.

2. Biologists are doing considerable tracking and telemetering of life signs, using both acoustic and RF signals. The "Underwater Telemetry Newsletter" discusses some of the work. Small, low-power devices are common.

3. The WHOI ocean engineers are involved in Arctic acoustic work that uses RF telemetry of broadband acoustic signals.

4. RELAYS and MOIST are two WHOI projects based on ARGOS telemetry of data; RELAYS is a drifting surface buoy with an instrumented cable beneath, and MOIST is a subsurface mooring with a RELAYS-like surface expression as a telemetering link. Both have a UHF link for short-range 300 baud SAIL-protocol interrogation and control from a nearby ship.

5. ARGOS and GOES are two satellite-based data links that are quite different in capability. ARGOS is a polar-orbiting system based on a NOAA satellite; it provides low one-way data rates and position fixing on a sporadic basis (a few passes per day), with worldwide coverage. GOES is a geostationary satellite with limited coverage, but permits high data rates and two-way channels. Both are being used in oceanographic applications. especially ARGOS for drifting buoys.

6. Various LORAN-C drifters receive the LORAN-C signals and telemeter them back to shore (sometimes via HF) for tracking.

7. At Scripps, Russ Davis has built small drifters that transmit a VHF signal that is tracked by triangulation from two shore sites. A small airplane has also been used for tracking. A new version of the drifters will use ARGOS tracking.

8. At WHOI Spindel, Liberatore, and Schuler have built a prototype acoustic modem operating at 45 kHz over a 1.5 km deep water path; the data rate is 300 baud. No problems have been encountered with reverberation. A lower frequency and slower data rate should permit operation at full water depths.

9. Off Martha's Vineyard, a project by Sandy Williams telemetered bottom stress data by VHF because the data volume was too large for *in situ* recording.

10. Another Williams project used bottom tripods that could acoustically command one another for the purpose of switching to a faster sampling rate if a tripod began to sense a high-energy event in the boundary layer.

11. The Neil Brown Instrument Systems Smart CTD and Smart Acoustic Current Meter have the option of a two-way acoustic link for control and some readout.

12. A joint project between WHOI (Spindel) and the University of Michigan (Birdsall) is concentrating on long-range acoustic telemetry: 1000 km or more at 10 bit/s.

13. There is a class of "smart drift bottles", such as the RAFOS (that is SOFAR spelled backwards) float from Rossby and Dorson at URI: it listens to moored sound sources and pops to the surface to yield its position via ARGOS and transmit its past positions.

14. A moored spar buoy has been deployed in locations sometimes covered with ice; when the ice leaves the spar pops up and telemeters its information. It leans over and submerges when the ice returns.

15. Analogous to the "smart drift bottle" is the "smart fish", a device that follows some prescribed path or maintains some prescribed position, and which telemeters its data back to the investigator. Various forms of this have been attempted, but no current device exists except for programmed subsurface bodies like SPURV from the Applied Physics Lab at UW.

16. A NOAA project is concerned with XBT's on ships of opportunity that telemeter the data back via GOES. The XBT's are held in a cluster and launched automatically.

17. A Pacific tsunami-warning network is being established with automatic sensors and telemetry.

Summary. Many RF and acoustic telemetry projects are in progress. They can be categorized as those which provide real-time or near-real-time data, those which provide remote recording of data, and those which lessen the risk of an experiment.

Future Projects and Miscellaneous Ideas and Comments

1. Pop-up-buoys: devices that are released from a fixed position on a periodic basis, and are then tracked as surface drifters. They permit constant reseeding of an oceanic site instead of once-off experiments. Also, pop-up tops to subsurface moorings, i.e. ballast-changing telemetry modules that can rise to the surface to provide sporadic telemetry. One version from CSDL (Dahlen) can make about 200 round trips from 200 m.

2. The Progress-Reporting Ocean Mooring (PROM) is a plan to acoustically telemeter deep ocean data to the top of a subsurface mooring, where it would be loaded into data capsules. A capsule would be released periodically to float to the surface and telemeter the data home; if ARGOS were used, the data float could also be tracked to give surface currents.

3. Amplitude acoustics: most acoustic telemetry systems make use of frequency shifts or pulse modulation to transmit information, but there may still be some value in amplitude modulation.

4. Very low frequency (VLF) electromagnetics might be a way of getting information to or from a submerged instrument. Even though the efficiencies and skin depths are small, there are tradeoffs due to the great propagation ranges in the air.

5. Future satellites are being planning without any consideration of the data needs of oceanographers. We are a small user community and have no voice, which means we may have to take whatever is left over from the needs of other communities, for example commercial shipping and oil exploration.

6. More use of power from the ocean (e.g., wave action) may aid the power needs of some telemetry projects.

7. Meteor scatter is a possibility for over the horizon VHF/UHF telemetry without use of satellites.

8. Near-surface ducting of VHF signals may provide some long-range telemetry over the ocean (Brooks, 1984).

9. Project Dumand and its spinoffs examine nutrinos in the deep sea. Maybe there are other communication schemes we haven't looked at.

10. Optical methods are almost untried in oceanography; fiber optics are used but they are a hard link. Soft links like lasers can communicate lots of information but are unused.

11. HF telemetry became unpopular some years ago due to its lack of world-wide coverage, noisy channels, and the difficulty of using high data rates. But many experiments do not require great coverage or much data, and we now have available microprocessors to help with error-detecting protocols, space (receiving) diversity, and spread-spectrum techniques. It may be time to reexamine the use of HF telemetry in oceanography, especially considering the decreasing number of satellite channels available to us.

12. Perhaps there should be some frequency bands allocated specifically for oceanographic data use, in HF/VHF/UHF and satellite bands.

13. The needs for telemetry seem to break into two main categories: data transfer and position fixing. An example of not demanding that the same system do both tasks would be to have a GOES and an ARGOS transmitter on the same platform; GOES would handle the high data rate and ARGOS would give the platform position.

14. The needs for data during an experiment or deployment categorize as real-time data or progress reports. The former are typical of situations demanding detailed adaptive experimentation or for operational monitoring; the latter are sufficient for performance assessment or to reduce risk or for slowly changing conditions.

15. SOFAR floats have acoustically telemetered temperature and pressure since 1975; almost 200 platform years are now available and one float has been operating for 7 years.

<u>Summary.</u> The ideas and comments are related to new ways to telemeter, especially if satellites are not involved, and to ways to get data back from subsurface instruments, which is recognition of the difficulty of maintaining things on the surface of the ocean and the likelihood of long, deep experiments in the future.

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APPENDIX D: METEOR-BURST DATA TELEMETRY FOR OCEAN RESEARCH

Melbourne G. Briscoe

26 July 1985

What is Meteor-Burst?

Each hour millions of tiny meteors enter the earth's atmosphere and produce ionized trails that can scatter radio signals. Meteor-burst, or meteor-scatter, is a communications scheme based on this phenomenon. The idea has been around since the 1920s and was first tried as a communications channel in the 1940s.

The trails are typically 25 km long and greater than 1 meter in radius, with electron densities from 10^{10} to 10^{15} electrons per meter of trail, depending on the meteor size. The meteors themselves are most prevalent during August mornings, and most scarce during February evenings, by a ratio of about 12:1.

Most of the trails are sufficiently weak ("underdense") that the scattering mechanism for radio waves is actually a reradiation of the signal by the electrons acting as dipoles excited by the incident waves. The maximum angle of radiation is therefore equal to the incident angle, and the duration of the scattering is a few hundred milliseconds to a few seconds.

The height in the atmosphere at which the meteor trails occur is some 85-115 km, which is between the D and E layers of the ionosphere. This sets the geometry for the coverage area of meteor-burst communications: the maximum range is about 2000 km for two points on the surface to share a common view of a trail, and the range at which the two points share the greatest amount of common sky is some 600-1300 km.

In a typical operation, the master station continuously emits a coded beacon in the 40-50 MHz region, using 500-1000 Watts of RF power. When the remote station (100-300 Watts) hears the beacon, which signifies that a path exists between the master and the remote, it bursts data at some 10 kbit/s for a fraction of a second and listens for an acknowledgment from the master. The data stream contains a checksum so that the acknowledgment is of having received the data packet correctly, not just of having heard it. This bursting and acknowledging continues until the path disappears or the data at the remote station is all transmitted.

Performance of the link depends upon the "wait time" between usable scattering events, the "decay time" of the events, and the antenna gains. The single parameter that best describes performance is the data throughput: tests have shown that this can be some 100 bit/s on average, which suggests a 1 percent link efficiency.

For comparison, an ARGOS terminal transmits 256 bits per burst, with a mid-latitude maximum of about 100 bursts per day (ten bursts per pass, 10 passes per day), which gives about 0.3 bit/s on average; the ARGOS

throughput is actually lower than this because redundant data transmissions are required to assure low error rates. ARGOS is available worldwide, and platform location is possible, so the tradeoff between meteor-burst and ARGOS depends on the particulars of the application.

History

Even though the Canadians had installed an operational meteor-burst system in 1954 to link their sparsely populated north country, by the 1960s the interest in meteor-burst began to diminish: satellite channels were becoming available, and voice and facsimile transmissions were not suited to the sporadic and transient meteor-scatter paths. Also, the amount of intelligence that had to be placed at a remote site to control the short, bursting, digital transmissions was still not economical.

In the late 1970s, however, microprocessors made it easy to deal with the intermittent channel, solid-state transceivers were economical, and communications needs were understood to include certain kinds of data telemetry where strict real-time transmission was not necessary and where satellite channels were not possible or appropriate.

Present

There are four major operational meteor-burst communications systems in the United States, and others elsewhere. Many kinds of experiments have been run to understand the propagation characteristics and data throughput, and commercial equipment is available.

The oldest of the U.S. systems (1974) is the Alaskan Meteor Burst Communications System used by 5 Federal agencies; it is functional even during the auroral disturbances that disrupt normal HF propagation. Over 50 remote sites are involved in the data collection process (Anon., 1985).

Snowpack Telemetry (SNOTEL) was instituted in 1977-78 by the Department of Agriculture to collect water resources data from 500 solar-powered remote stations in 11 western states. Some 16 sensors gather data at each site and microprocess it into 15-minute averages for transmission (Barton, 1977; Sytsma and Jolly, 1982; Smith, 1984).

The Federal Emergency Management Agency (FEMA) is installing meteor-burst links to all 50 state capitals; they are attracted to the possibility of not needing satellites and of being able to communicate through severe ionospheric disturbances (Anon., 1985).

The Northern Natural Gas company is using meteor-burst to monitor the status of its oil pipeline between Houston and the Great Lakes (Anon., 1985).

Oceanic Uses

Apparently no oceanographer has used meteor-burst in any way, although Dale Pillsbury at Oregon State is beginning tests of a simple wave buoy with a quarter-wave whip on it, installed in a convenient pond near Pillsbury's

laboratory. The buoy will act as a remote station to an Alaskan or Canadian master station.

The main reason to consider meteor-burst for oceanography is the large data throughput that is possible. The typical drifter buoys used in the past gave perhaps hourly values of (say) two 12-bit samples, which is equivalent to less than 0.01 bit/s on average and can easily be handled by ARGOS, with position as well. Newer drifters like RELAYS have higher data rates and use up to four sequenced ARGOS IDs, plus data commutation, to achieve the required data throughput of about 0.5 bit/s.

A moored surface buoy in typical usage (6 current meters with temperature sensors and a meteorological package at the surface) will need about 2 bit/s throughput; plans for doppler acoustic scattering sensors on moorings and drifters will push the requirement to 50-100 bit/s for a few-minute average from the sensors. It seems that the ARGOS channels are barely adequate today, and inadequate for tomorrow. Note also that 50 bit/s gives 4.3 Mbit/day, which will fill the typical Sea Data cassette in three days. Telemetering and remote recording will be required in these high data-rate experiments.

One implicit convenience of meteor-burst is the time-sharing of its frequency allocation: hundreds of remote stations can be monitored without difficulty because the signals both ways can have coded headers. That is, the master can interrogate only certain remotes during a given time interval, and then switch to another set of remotes during the next time interval.

The possibility of communication both directions also means that experiments can be modified on command from home. Note that all the intelligence for a remote station need not be physically at the remote station: some decisions can be made and implemented based on information from many stations, not just the one to which the command is addressed.

Meteor-Burst Coverage of the North Atlantic Ocean

Meteor-burst has a 2000 km maximum range and a 600-1300 km optimum range. Master stations placed around the North Atlantic and on mid-ocean islands can cover the entire ocean.

A minimum coverage system allows each part of the ocean surface to be within 2000 km of a master station. A linked coverage system allows the master stations to communicate with each other, which in turn allows any point on the ocean surface to have its data relayed back to any of the master stations entirely by the meteor-burst communications links.

The priority for station installations in order to achieve a linked coverage of the North Atlantic, starting with the vicinity of the Gulf Stream, is shown in Figure D-1 along with a schematic chart of the location of the stations.

Technical Information Needed

Unlike the terrestrial meteor-burst systems, where the antennas at both the master and the remote can be as elaborate and directional as needed, an

oceanic remote station would typically have a zero or low-gain omnidirectional antenna. One definite advantage of the oceanic antenna, however, is the sea surface itself acting as an excellent ground plane, which means that vertical antennas perform very well.

The principal area of technical research needed is on data throughput as a function of antenna type, remote location, and the power level and consumption of the remote.

For example, a vertical antenna on a buoy will have a low angle of radiation, and thus be good for long range transmissions. A pair of crossed horizontal dipoles on a buoy will have a steeper angle of radiation and thus be better for shorter range contacts. The master station, however, must have a horizontally or vertically polarized antenna system to match what is on the buoy. Which will work better at various ranges, and how much power is needed to achieve 50 bit/s average throughput? 100 bit/s?

The waiting time between usable paths is also important because it determines the size of the storage buffer that is needed in the remote station. And the decay time of the path determines the optimum message length. One way to gain the needed technical background would be to put a remote station on an oceanographic ship working in the North Atlantic, and meteor-burst data from the ship back to land. Different antennas and power levels could be tried, and experience would be gained in the equipment, the propagation, and the data handling. The data could be either known signals so that bit error rates could be calculated, or could be the ship's SAIL data with meteorology, ship location, etc., built into the data stream. A combination of both approaches would be ideal.

Costs of Meteor-Burst

Only two companies currently market meteor-burst equipment, although amateur radio operators routinely use the propagation mode in their 50-54 MHz band. The companies are:

1. Meteor Communications Corporation
   22419 72nd Avenue South
   Kent, WA 98032
   Tel. (206) 872-8890

2. Vaisala Oy
   PL 26
   SF-00421 Helsinki
   Finland

   in the U.S.: Vaisala, Inc.
   2 Tower Office Park
   Woburn, MA 01801
   Tel. (617) 933-4500

In very round numbers, the MCC master station runs \$60k and the remotes are \$6-8k, depending on the version. The Vaisala equipment is more costly, at \$40-100k for the master and \$20k for the remotes. However, the Vaisala remotes are complete stations with towers, 6-element yagi antennas, and power supplies.

Both systems work in the 40-50 MHz range, hence the transmitter and receiver technology is not difficult. The market is currently small, hence the prices are high. Any large market for the remotes would surely bring the prices down. Note that the MCC remote costs about what an ARGOS remote did just a few years ago.

Licensing

There is no specific FCC allocation for meteor-burst communications. Experimental licenses are available in the bands 42.0-46.6 MHz and 47.0-49.6 MHz, on a not-to-interfere basis with the land mobile primary usages of those bands. Each master station location and remote station location would have to be examined to insure that the meteor-burst frequencies do not interfere with other users in those locations. If the remotes were all in oceanic locations, then only the masters would have potential frequency problems.

FCC form 442 (available from regional FCC field offices) is the means of making application for an experimental license.

WESTERN ATLANTIC CHAIN

1. WOODS HOLE, MASSACHUSETTS
2. MIAMI, FLORIDA
3. ST. JOHNS, NEWFOUNDLAND
4. PUERTO RICO
5. BERMUDA

NORTHERN ATLANTIC CHAIN

6. FREDERIKSDAL, GREENLAND
7. REYKJAVIK, ICELAND
8. TROMSO, NORWAY

EASTERN ATLANTIC CHAIN

9. BREST, FRANCE
10. AZORES ISLANDS
11. CANARY ISLANDS
12. CAPE VERDE ISLANDS

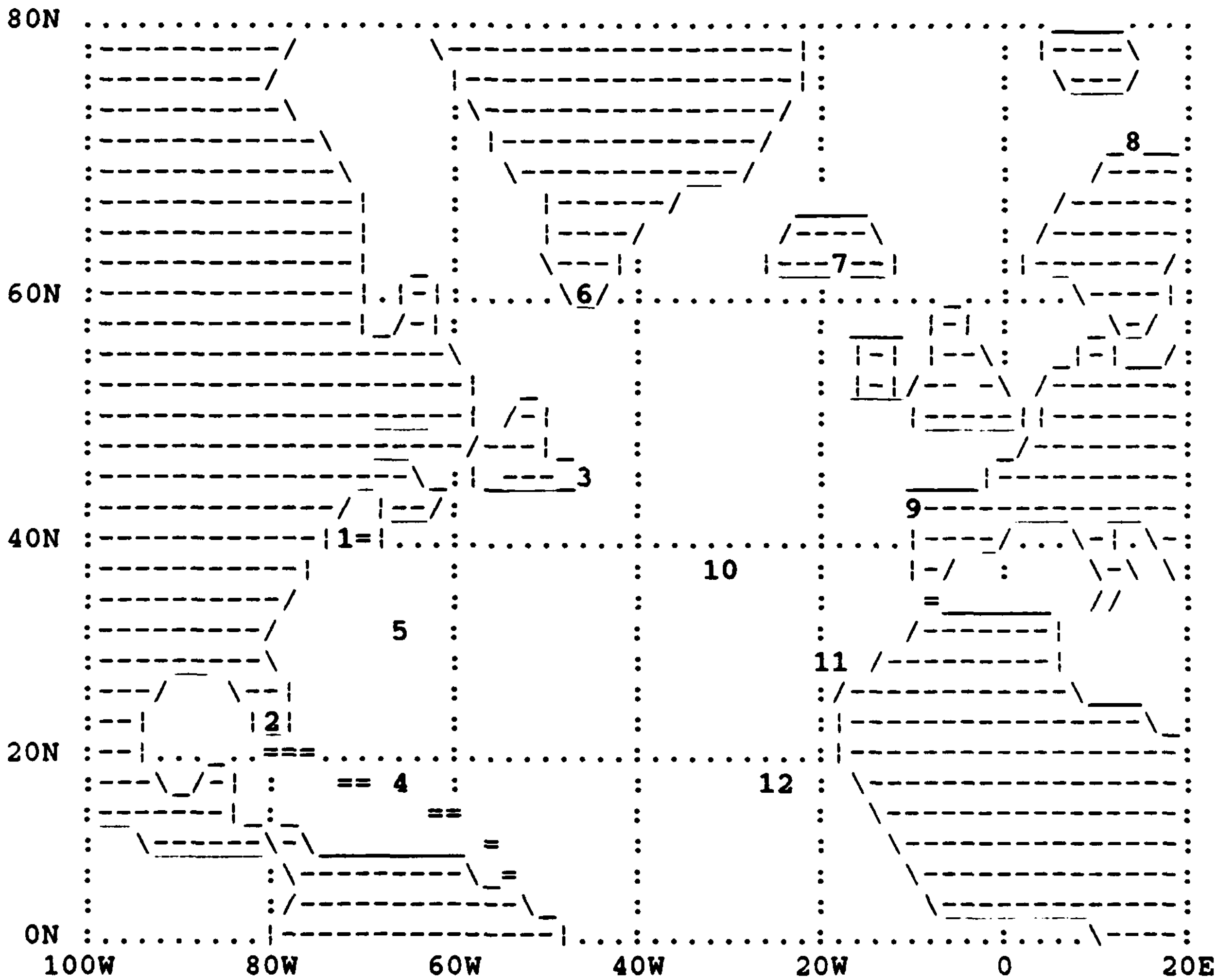

FIGURE D-1: Schematic of North Atlantic with meteor-burst master stations indicated; see listing above for locations to go with the numbers. 20 degrees of latitude is 2222 km, which is about the maximum range for meteor-burst.

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APPENDIX E: GEOSTAR STATUS REPORT

Melbourne G. Briscoe

23 November 1985

GEOSTAR is a new, commercial position-fixing and two-way data transfer service that works through two geostationary satellites using spread-spectrum RF technology. Unlike ARGOS, which uses the TIROS series of polar-orbiting satellites and requires a stable oscillator in the platform so that a doppler shift calculation can be made on the signal received at the satellite, GEOSTAR uses two stationary satellites and simply ranges on the platform's transmission.

A ground computer at GEOSTAR central (Princeton, NJ) transmits general interrogation signals through the two satellite relays, many times per second. The platform transceivers will constantly display a goodness-of-reception indicator. If the platform wants to know where it is, it sends a request for its position; the two satellites hear the request, relay the reception times to the ground computer which calculates the platform position and which sends the position back to the satellites for relay to the platform.

Or, the platform can transmit data and get an acknowledgment back through the system that it was received! And messages can be sent to the platform, too. Finally, an investigator at home can ask the ground computer to locate all his platforms; the computer uses the distinct IDs built into each platform to locate them and send all the locations back to the investigator.

The system has received FCC approval and will begin in August 1986 with "LINK ONE", a forerunner system that will have only one-way data transfer from the platform to the user's headquarters. No messages can be sent to the platform other than the position interrogation request. The full GEOSTAR system will depend upon some new satellite launches and is expected in mid to late 1987.

The expected price for the GEOSTAR transceivers, which might be about the size of a pocket calculator and be powered by AA batteries, is $450. The anticipated prices for the early version LINK ONE equipment and usage is $2900, and it can be leased. The usage charges are $22.50/month/transmitter, with one transmission per hour allowed. There is an additional transaction charge of 2-6 cents per transaction. Each transmission from the platform is 32 characters, the same as allowable with ARGOS (256 bits, 8 bits/character).

I think what it all means is that with LINK ONE starting in August 1986 we can get hourly transmissions of 32 characters from a drifting or steaming platform, with positioning at 2-7 m accuracy (!!), for $2900 capital costs per platform and monthly fees of something under $66. This is to be compared with ARGOS that provides less than hourly information, no acknowledgment that the data were received correctly, three orders of magnitude worse positioning, about a third the platform cost, and about equal monthly costs to get your data tapes from France 2 or 3 weeks after the end of each month.

The big advantage of ARGOS is that it is worldwide, including near the poles. But the big advantage of GEOSTAR might be its acquisition and operational costs ($450 per platform!), its much better accuracy, and its 2-way data capability.

Ed Mellinger from Woods Hole has contacted GEOSTAR with questions about oceanographic uses, possible worldwide coverage, enhanced data rates, massive-user discounts, etc. Further information will be disseminated.

NOTE: All this information is from specifications and advertising material received from GEOSTAR Corporation, 101 Carnegie Center, Suite 302, Princeton, NJ 08540, telephone (609) 452-1171.

Some specifications for GEOSTAR are given in Table E-1 on the next page.

TABLE E-1: GEOSTAR Specifications

PARAMETER	VALUE	NOTES
Frequencies		radiodetermination
Bandwidth	16.5 MHz	each channel
Satellite-Users	2491.75 MHz	center freq RH polr
Users-Satellite	1618.25 MHz	center freq LH polr
GEOSTAR Central uplink	6533.25 MHz	
GEOSTAR Central downlink	5117-5183 MHz	
Modulation		
spread spectrum	Binary Phase Shift Keying	
chirp rate	8.192 MHz	
chirp period	122.07 ns	
coding	Pseudo Random Noise	
Signal Format		
GEOSTAR Central-Users		serial, computer controlled
Users-GEOSTAR Central	Spread Spectrum, Time Division Multiple Access	
Positioning		
Primary Method	2 ranges	Interrogation time and 2 response times, plus height from terrain map (altimetry encoded for aircraft)
GDOP	1.6-2.5	Typical
Ranging		Noncoherent delay lock discriminator
Tracking error	7.0 ns	rms combined in/out
Positioning error	2-7 m	typical (single shot)
inverse loop delay	1.7 Hz	double hop sat. link
backup positioning	3 ranges	
Satellites		
number of beams	7-14	typical
location		geostationary
Link Parameters and Data Rates		
Outbound (Sat-Platform):		2491.75 MHz downlink
GEOSTAR Central-Users (data rates per beam, with margins, for beam edge locations)	32-512 kbps	dependent on number of RDSS systems, for margins 3.3-9.3 db
Inbound (Platform-Sat):		1618.25 MHz uplink
transceiver power	40 W	flashlight batteries
transceiver transmit		hemispheric coverage
User-GEOSTAR Central (data rates per beam, beam edge)	8-16 kbps	
similtaneous transmissions	32	per beam, 3 db margin

APPENDIX F: TELEMETRY TRADEOFFS FOR OCEANOGRAPHY (preliminary version)

Melbourne G. Briscoe

18 May 1986

At present there are only a few telemetry possibilities from oceanographic ships and buoys: the polar-orbiting NOAA/ARGOS system, the geostationary GOES/METEOSAT/GMS and ATS satellites, direct line-of-sight VHF/UHF, over the horizon HF, and meteor-burst (M-B). Below I try and categorize each system and show the tradeoffs.

The "throughput" figures are averaged over a day; M-B, for example, actually transmits at 10 kbit/s, but the transmissions are sporadic.

TABLE F-1: Telemetry Tradeoffs

LINK	TYPICAL THROUGHPUT	AVAILABILITY/DAY	LONG-TERM AVAILABILITY (comments)
ARGOS	0.1 bit/s	every 1-3 hours	yes
GOES	1-5 bit/s	1-3 hours typical	yes (limited channels)
HF	50 bit/s	depends on range	yes (error checking)
M-B	50 bit/s	every few minutes	yes (error checking)
ATS	>1000 bit/s	continuous	no (limited channels)
V/UHF	>1000 bit/s	continuous	yes (error checking)

Each method above has its own typical geographical coverage. Only ARGOS is worldwide; GOES/METEOSAT/GMS (the Japanese geostationary satellite) cover all longitudes but miss the high latitudes (greater than 70 degrees); ATS is in the western hemisphere only and also has the high latitude limitation; HF can have worldwide coverage but with a low probability of getting data through; V/UHF is mainly line of sight; and meteor-burst is good to about 2000 km.

The ARGOS signals can also be monitored at one's own Local User Terminal, but only when the satellite is within a 2500 km radius circle from the LUT. Oceanographic use of the ATS series is on a shared basis with other services; the ATS series is now almost 20 years old and could fail at any time.

APPENDIX G: AN OPERATIONAL POLAR COMMUNICATIONS NETWORK

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A PRACTICAL APPROACH TO A POLAR COMMUNICATIONS NETWORK

ABSTRACT

This proposal for the establishment of a Polar Communication Network (PCN) refers to the use of polar-orbiting satellites to provide services that otherwise are unavailable with existing satellite systems. These services are becoming essential in order to perform the global science proposed for the 1990's and beyond, by NASA and NOAA programs such as the Earth Observing Systems (EOS). Rather than requiring a dedicated system of satellites, the PCN will fly dedicated transponder packages on polar-orbiting satellites of opportunity, providing a reliable, communication system for *in situ* observations, very economically. Estimates to design, build, integrate and test on a NOAA spacecraft, and operate, are on the order of several $100k, where any alternate approaches would cost millions.

Two types of services are required:

- 2.4 to 10 KBPS data transfers between simple ground antennas;

- Over 100 KBPS data transfers between steerable ground antennas.

A separate flight transponder will be used for each service. The PCN will relay data between any two ground-based users within a 1000 mile radius of the sub-satellite point. This will link the remote/mobile user to a central regional ground station with a geosynchronous satellite link and if desired, satellite image collection/processing capability, etc. Each satellite carrier will provide a full duplex service for the duration of a pass (typically 10 minutes). The link is not continuous, therefore, but it does allow a "burst mode" capability as often as there are passes. This will permit:

- Remote programming and interrogation of unmanned data collection devices;

- Collection of much higher volumes of data or two-way voice from selected sources using simple antennas (e.g. balloons, buoys, aircraft, field parties, etc.);

- Transmission of high volumes of ground truth data from the most remote regions to the composite data gathering centers in near-enough real-time;

- Dissemination of satellite image data to remote/mobile users.

Inherently the PCN will provide new communication services over the oceans of the world and over the high latitude regions. Ocean-based users are separated geographically and polar region users would see more passes per day. The link to a particular user would be initiated from the regional, manned station using the full duplex feature. Specific applications exist for the National Weather, Climate and Oceans Services, for the Solar-Terrestrial Physics communities, and for others.

BACKGROUND

Since existing geostationary satellite systems cannot service the high latitude regions directly, and since existing data collection systems servicing ocean regions and mobile users do not provide adequate full duplex, high volume data or voice capabilities, another system must be developed. These regions comprise over 75% of the world's surface area. The "holistic" type of Earth Sciences proposed for the 1990s and beyond require that these regions be brought into the global picture with as modern communications capabilities as possible. To date the constituency of users in these remote areas has not warranted the hundreds of millions of dollars that would be needed to develop a special satellite system to service their unique requirements. A "Catch-22" situation has existed where the level of effort is artificially constrained by lack of better communications, which in turn were not warranted by the level of effort.

A unique, practical, and remarkably cost-effective solution is available that uses polar-orbiting satellites, which cover the whole world every day and cross the polar regions every orbit. By carrying a dedicated transponder package, any polar orbiter can relay data between remote ground locations and ground stations in view of the geostationary satellites. These packages can be designed to fly on virtually any potential carrier with negligible impact on the carrier's primary mission. They can be provided for a few hundred thousand dollars and negligible operational costs. Spacecraft integration costs would depend on the particular carrier.

The techniques involved have been demonstrated by NASA and NOAA missions in the past, but they have not as yet become operational in the global sense proposed here. At present, low rate data collection systems such as ARGOS, GOES, and UOSAT/OSCAR have achieved operational status, but they have been constrained to focus on other specific pieces of the global communication needs. The PCN will complement these existing services. A successful demonstration of this PCN concept has been operating routinely between the South Pole, Antarctica and the USA since December 1984 (see article in 18 November 1985 *Aviation Week and Space Technology*). No further proof-of-concept is needed. Through the cooperative efforts of NASA, the National Oceanic and Atmospheric Administration (NOAA), and other scientific institutions, this system was conceived and became operational within one year. It utilized polar-orbiting earth resources satellites that happened to be carrying a ranging transponder that could double for ground-to-ground data relaying.

The global aspects and low cost approach of this concept make it very attractive to the NASA and NOAA science communities. A modest commitment on their parts could greatly enhance the global science planned for the polar platform era. The dissemination of satellite data to remote users, the inputting of more data from remote sources into the composite data centers, and the advent of "telescience" (remote control of ground-based instruments in conjunction with spaceborne instruments) capabilities in remote areas are prime examples. To date specific examples of needs and benefits have been expressed from science communities such as the Earth Sciences, Solar-Terrestrial, Oceans, Climate, and Weather.

SOLUTIONS

There are four satellite solutions to be considered:

1. Communications satellites in inverted Molniya (high altitude polar) orbits:

   - USSR uses this approach for high latitude communications in the Northern Hemisphere.

2. Communications satellites in geosynchronous low inclination orbits:

   - Advanced Technology Satellite (ATS) 3 and Lincoln Experimental Satellites (LES) 8 and 9 are existing examples.

These two systems can provide full duplex communications for about 40 percent of the day per satellite. Their high altitudes will necessitate large ground-based antennas, high power outputs, and steerable antennas, to allow 100KBPS data rates. Randomly, such satellites have become available but they are partitioned into many low rate (100BPS to 2.4KBPS) channels and they are episodic. A dedicated satellite system of this type will cost hundreds of millions of dollars and will not be warranted by the ocean and polar regions for some time. This eventual "best" solution appears to require too large a first step. More feasible solutions involve dedicated flight packages for planned missions.

3. Low Altitude Polar-Orbiting Data Collection Satellites:

   - US developed this concept and the French have also built operational systems. Data is collected on-board, stored, and dumped later to a key ground station. These systems are designed to collect short messages (e.g., a few hundred bits) from thousands of sources. Another system is needed to accommodate those users (ships, balloons, etc.) who desire a high volume data link, a voice link, or remote commanding.

4. Low Altitude Polar-Orbiting Data Relaying Satellites:

   - Data is relayed between two ground stations during 10 to 15 minute windows of co-visibility. This is the primary solution we are recommending, because of its relatively low cost and ease of implementation, and because of its evolutionary potential. The technique inherently applies to any remote location, and is particularly useful in polar regions where there are no geostationary services. Frequency spectrum allocations are of key concern if this technique is to be employed worldwide.

Low altitude polar-orbiters can provide a full duplex communications channel to polar ground stations in "burst" mode (once every orbit). The low altitudes will dramatically simplify the ground stations (25 times closer than geosynchronous satellites) and reduce their costs to build and maintain. A dedicated communications satellite is not required. Any polar-orbiting carrier that can accommodate a transponder package will suffice. A system costing about $250K (if purchased commercially) per satellite that can be implemented within a year, is warranted by the projected demand. While this system will not provide "continuous" coverage, data relaying will provide the two essential services: 2.4 to 10KBPS two-way data and voice links between remote users 1000 miles apart, using simple, fixed antennas; and at least 100KBPS data links between remote ground stations in near enough real-time, where steerable antennas are feasible. Suitable data links can then be made from a remote central, manned ground station to anywhere covered by the conventional geostationary satellite system.

The flight hardware can evolve in stages to easily meet future polar and remote location communications needs including those of balloons, aircraft, field parties, and unmanned ground-based geophysical observatories in the polar regions. In conjunction with existing geostationary systems, a Polar Communications Network (PCN) of this sort, will immediately provide complete global (near enough to real-time) communications throughout the foreseeable future.

INITIAL COST ESTIMATES

NASA/Goddard has the capability of designing and building a protoflight transponder package for about $100K and a man-year or so of effort (about $280K if purchased commercially). We propose to fly such packages on as many NOAA spacecraft as possible starting as early as 1988 and carrying onto the Polar Platform(s). Analyses, fabrication of special spacecraft interfaces, integration and testing on the first NOAA spacecraft would be about $500K, but follow-ons would cost much less. This includes fully redundant packages, RFI analyses and tests, design and fabrication of an appropriate spacecraft interface box and an ARGOS-type deployable UHF antenna system, and the harnessing, integration, and testing efforts. Operational costs are negligible for the spacecraft, since the data handling is done on the ground only.

Ground-based users determine their system costs by the date rates they desire, independent of the flight hardware. A typical two-way UHF transponder system suitable for 2.4 KBPS costs about $25K.

BENEFITS OF INSTALLING AN OPERATIONAL POLAR COMMUNICATIONS NETWORK (PCN)

In the National Interest

Antarctica is a specific example of a vast area of the world that is in extreme need of improved communications. This continent alone has a major input to every global science proposed by NASA and NOAA for the Polar Platform.

U.S. goals and policy regarding Antarctica have demonstrated a consistency over many decades as documented in numerous policy reviews and statements. Most recent is the White House Memorandum of February 1982 which reaffirmed the United States' policy in Antarctica. Representative of that policy are the following objectives:

- To maintain the Antarctica Treaty and ensure that this continent will continue to be used only for peaceful purposes and shall not become an area or object of international discord.
- To foster cooperative scientific research for the solution of worldwide and regional problems, including environmental monitoring, prediction, and assessment of resources.
- To protect the antarctic environment and develop appropriate measures to ensure the equitable and wise use of living and nonliving resources.

More effective communications to Antarctica (and likewise to the arctic region) are becoming essential in order to achieve these objectives in the future. Greatly increased international interest and activity in the antarctic region have increased the potential risk of impacting the environment very quickly. Higher data volumes, to more places, in more near real-time are needed.

The continent of Antarctica, in particular, is dedicated to science on an international basis. These modern communications will enable cooperative scientific research throughout the continent, which correlates directly with Space Science in the Polar Platform era. The U.S. has an opportunity to take a leadership role in applying our space-developed technologies to the last frontiers on Earth for the enhancement of World Science Productivity. Conversely, new spaceborne scientific instrumentation (e.g. Side-Looking Radar) has been projected for the Polar Platform era to correlate with new opportunities for enhanced ground-based science.

Enhanced Science Productivity

Effective, modern communications throughout the Polar regions will reduce the inherent environmental limitations on science in those remote areas. Available space technology can be applied to enhance the ground-based science by enabling high volume reliable communications to remote manned and unmanned ground stations in near-enough real-time. This will enable "telescience" and space/ground-based science interactions, bringing the Polar regions into the Global picture. Without modern polar communications, all our studies of Earth processes (weather, climate, air quality, upper atmospheric/magnetospheric interaction with the sun's atmosphere and magnetosphere), and other related extra-terrestrial phenomena is severely constrained.

An Interagency "Plus"

NASA and NOAA share a common science community nationwide. Each agency has a unique set of resources that are already being applied to assist this community. By cooperating to develop an operational PCN, they will save the US government time and money towards this end. Existing technology will find new applications (e.g., multiple use of polar-orbiting satellites), improving agency productivity and providing excellent public relations. This effort to apply space technology to the oceans and polar regions, in general, will stimulate the development of new technology and applications for the polar platform era. The long-term commitment to bring space technology to these remote regions will spawn a number of new cooperative efforts. For example, unmanned geophysical observatories (UGOs) on the ground could be built like spacecraft in order to perform correlative science in a similarly harsh environment. Such efforts will also stimulate high agency morale with quick response projects of high visibility that also serve as excellent training for young engineers.

In the next decade, scientific research will necessarily assume a global perspective. This "holistic" understanding of our environment is a multi-agency effort by definition. Global communications is a prerequisite tool for the tasks ahead. Interagency cooperation between NASA and NOAA to develop this tool is mutually beneficial and in-line with similar precedents such as satellite data collection, weather forecasting, earth resources studies, geostationary communications, etc.

Evolutionary Potential

The PCN can evolve to provide greater services as the number and sophistication of the flight transponder packages increase. Data rates up to 500 KBPS and almost hourly transmission opportunities are reasonable evolutionary projections. Also, additional services to more mobile or unmanned users including international scientific groups, can be provided as the user constituency is developed. The full duplex feature allows various opportunities for reprogramming and interrogation by remote control. It also allows a central manned base to determine which of the accessible users is to be interrogated. There is natural geographical isolation of users in the

non-polar regions, while more passes per day are available to handle the concentration of users in the polar regions.

The current store and forward systems have been limited to low data rates (100 to 400 BPS) and short messages, mainly due to the need to conserve on-board satellite resources (e.g., data storage and power). With the PCN, the ocean research community, for example, could burst 2.4 KBPS data from remote, non-polar data collection platforms (DCP) to a manned system within 1000 miles for onward relay through the geostationary satellites. There is little impact to spacecraft, because the "Store and Forward" resources are on ground. A user can elect to upgrade his ground-based equipment to handle voice or higher rate data, without impacting the flight hardware. Some existing HRPT ground stations, if modified, would be usable as central, manned store and forward centers for many DCPs in a 1000 mile radius. Furthermore, a central HRPT station could send satellite image data to a ship in the area at a rate (e.g., 10 KBPS) that could be accommodated by a fixed antenna.

When the user constituency warrants it, an RF switch could be added to the flight transponder package, enabling a satellite-to-satellite link option. At that time, high frequency data from the ground could be picked up by some low altitude polar-orbiters and relayed through their on-board system to an otherwise inaccessible geostationary satellite and onward to anywhere in real-time bursts. Spacecraft transmission time rather than on-board data storage resources are a factor. Given appropriate interagency agreements, NASA's geostationary Tracking and Data Relay Satellite System (TDRSS) might be used to minimize the cost of transmitting scientific research data in this manner. In the lower latitudes (below 71 degrees) a direct ground link to TDRSS' multiple access relay system is possible.

RECOMMENDED APPROACH FOR IMPLEMENTING THE PCN

Given the experience and expertise of NASA and the Goddard Space Flight Center (GSFC) in initiating innovative space technologies for the improvement of science, it is reasonable that NASA take a leading role in developing the protoflight standard transponder (PST). After the design, fabrication, and testing of the PST at Goddard, the technology would be transferred to NOAA and NSF to be mass produced for operational missions such as NOAA-K,L,M and the Polar Platform.

It is noted that NSF has agreed to fund the out-of-pocket costs of this PST if NASA/GSFC will commit the required in-house manpower. This approach will substantially reduce the time required to have the PST available for the next carrier of opportunity. In fact, the PST could be ready by the end of 1986, in time to be integrated onto the next available spacecraft.

A typical low altitude polar-orbiting spacecraft is an ideal carrier for this "add-on" mission, if it meets the following criteria:

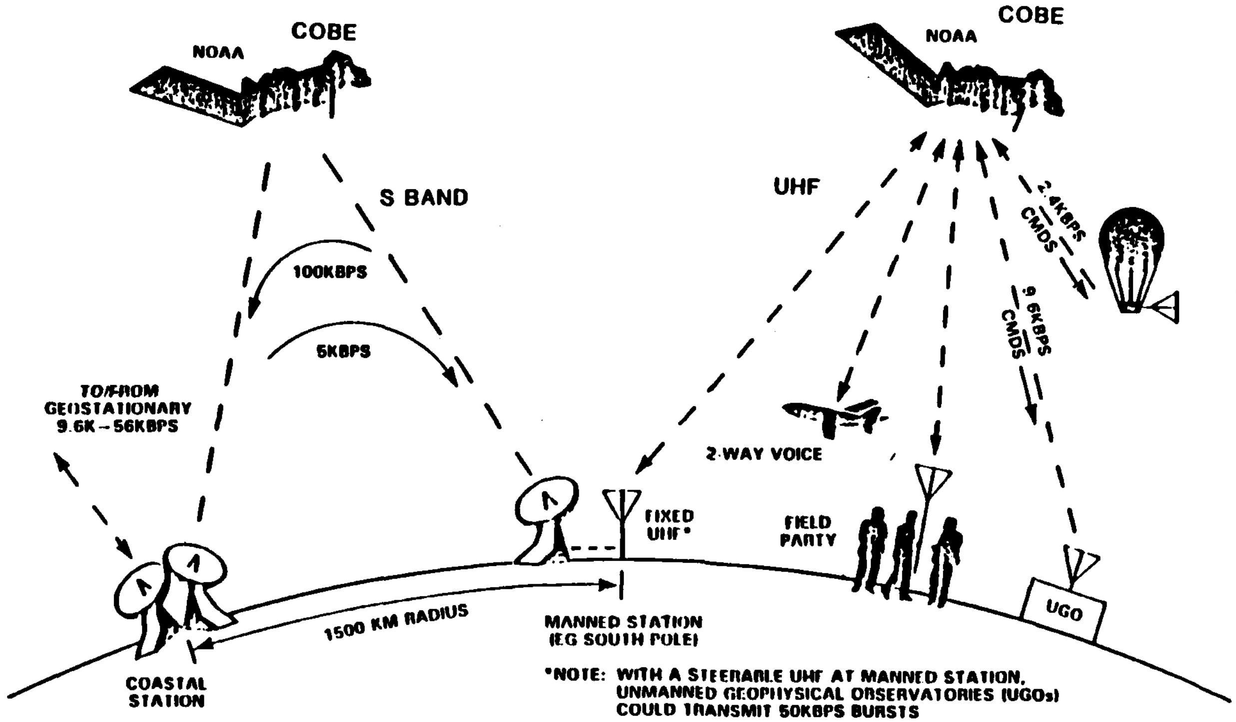
- 600 km to 1200 km circular orbit (sun-synchronous preferred);
- One end of the spacecraft always facing down;
- Space available to accommodate two 1x1x0.5 ft PST packages (double for full redundancy);
- A power source (e.g., solar array) large enough to accommodate the 25 watts required when "ON". The PST could be operated on a non-interference basis to avoid any power/thermal concerns during the primary mission.
- Full redundancy and other provisions intended to ensure a long usable life and not requiring expendables to maintain its orbit or orientation are desirable features;
- A primary mission which is compatible with the unique requirements for this new communications function (e.g., RF compatibility, frequency spectrum allocation, thermal dissipation of about 20 watts when operating, a clear field of view of the Earth over a 60 degree cone angle and a nearly clear field of view over 120 degrees:

o A slow spin rate to minimize Doppler effects from off-axis antennas:
o Thermally controlled areas for the flight electronics of -10 to +50 deg C;
o Weight allowances for 15 pounds per package (i.e., one S-Band and one UHF transponder).

In its simplest case the package requires only ON/OFF commands, no telemetry monitors or other on-board resources, and if a thermally controlled area is available then no other active thermal is needed. The addition of such devices would possibly justify an extended mission for a given carrier. To control costs in an extended mission, a NASA/NOAA sponsored university could perhaps be contracted to "fly" the satellite after the primary mission. Here is an ideal example where an existing mission can greatly increase its productivity with little impact, given the proper interagency cooperation now. Lessons learned in this PST effort will enable a smooth transfer of technology to NOAA, and later to other space agencies and to private industry when warranted.

The task ahead is to begin to implement the PCN one flight package at a time while the multi user community develops. A long term agreement between NASA and NOAA, which have responsibility for space science research and technology, and the National Science Foundation (NSF), which has national responsibility for ground-based polar operations, is called for. These agencies already share overlapping scientific interests. Their inherent resources can again be shared in this effort to markedly improve their global scientific productivity, while saving the US government time and money, and maintaining technological leadership for the US in global communications. We are actively encouraging the immediate and long-term commitments of these agencies towards this common goal.

DATA COLLECTION FROM MOBILE/UNMANNED UNITS (POLAR REGIONS)



<u>THE STANDARD TRANSPONDER HAS TWO PARTS:</u>

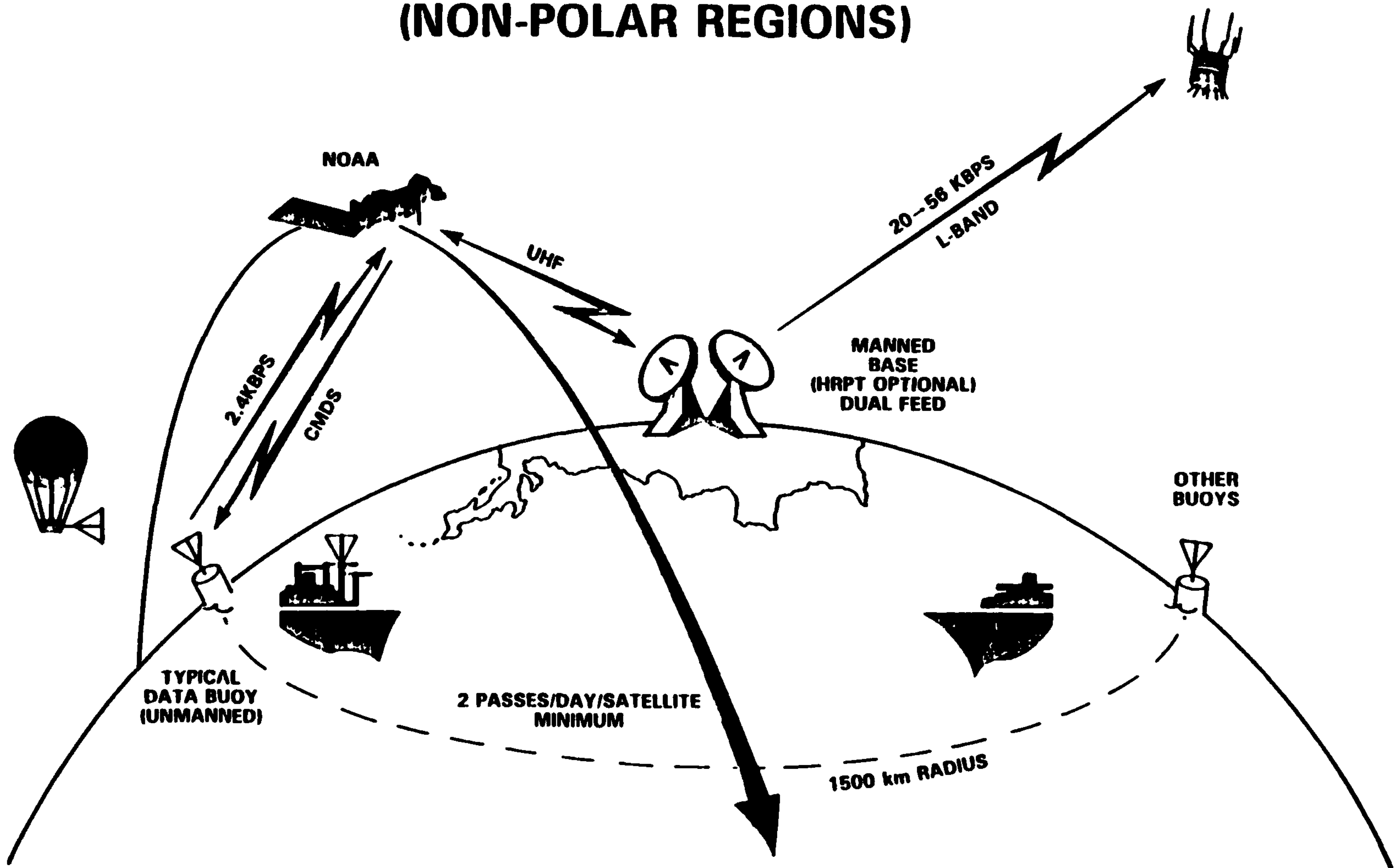
S-BAND TRANSPONDER

* RELAYS THE DATA STORED AT MANNED STATION TO A STATION WITH A GEOSYNC LINK TO U.S.
* STEERABLE ANTENNAS ALLOW HIGH DATA RATES

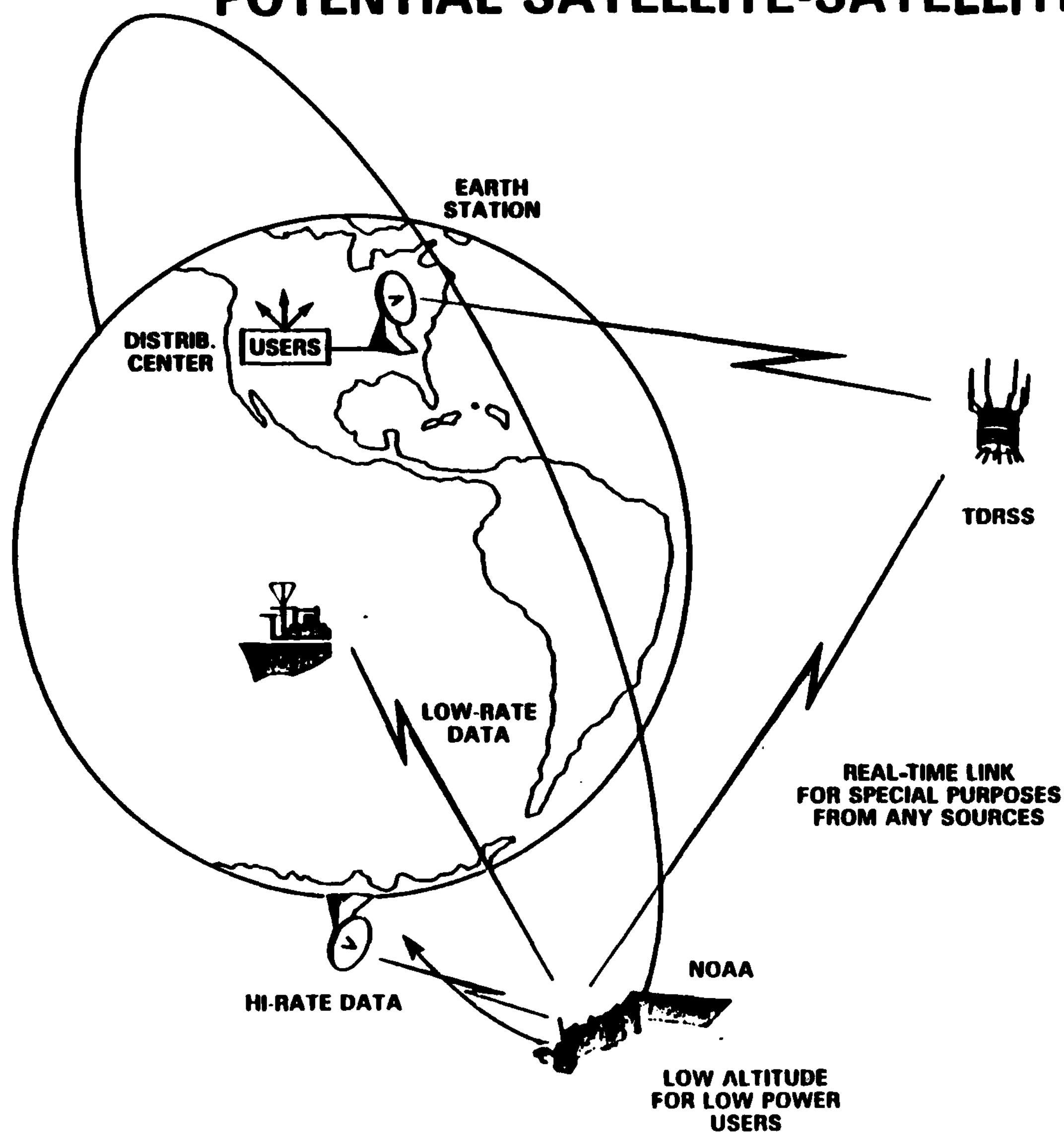
UHF TRANSPONDER

* RELAYS DATA FROM VARIOUS MANNED & UNMANNED SOURCES TO MANNED "STORED & FORWARD STATION
* LOW DATA RATES ALLOW SIMPLE ANTENNAS

DATA COLLECTION FROM UNMANNED BUOYS/BALLOON/SHIPS (NON-POLAR REGIONS)



POTENTIAL SATELLITE-SATELLITE LINK



APPENDIX H: HF PACKET RADIO WITH DIVERSITY RECEPTION

Melbourne G. Briscoe

SUMMARY

Twenty years ago the high-frequency band (3-30 MHz) for ocean data telemetry was dropped in favor of schemes utilizing satellites. The primary difficulties with the HF methods were the constantly changing propagation, and the noise and interference on the signal even if it did arrive at the destination.

Recent advances in digital radio technology have made it possible to reconsider the use of HF telemetry. In particular, packet radio techniques permit error-checking of transmissions and the certainty that bit error rates will stay below 1 in 10^{12}. The methods and equipment to do this are now common in amateur radio usage and cost less than $200. Two-way handshaking is required, but the addition of a receiver to a remote station is not a major item.

The other change in methodology that allows HF telemetry to be reconsidered is the concept of diversity reception. That is, the signal from the remote platform may not propagate to the desired receiving station, but the chances are that it propagates somewhere else where it can be heard. A network of receiving stations then increases greatly the chance of hearing the transmissions from the remote unit, and packet radio protocols insure that the received data will be error free.

A development program would begin with a field test of the concept of HF packet telemetry from sea, with diversity reception. Although the link rate while the path is good is 300 baud, what is the actual link efficiency? How many diversity receivers are needed to make the data throughput acceptable? How many platforms at sea are needed to amortize the network of receiving stations? And how does one coalesce the data from all the receiving stations into the one or more sites that want access to the data?

The first opportunity for a field test will occur during an ONR sponsored exercise in October 1986 called PATCHEX, during which an oceanographic research ship will be in the eastern North Pacific Ocean, northwest of Los Angeles. On a predetermined schedule, and using amateur radio equipment on the amateur radio bands, a roster of shore HF packet stations will attempt a packet "connect" with a ship HF packet station. Digital messages will be exchanged in a simulation of data telemetry. The analysis of the exercise will attempt to estimate the probable efficiency of the link, as a function of the number of receiving stations that might have been available at any given time.

Six HF frequency bands are internationally allocated for ocean data transmission. These six bands, at 4,6,8,12,16, and 22 MHz, would be available for an operational HF packet data collection network.

INTRODUCTION

Twenty years ago the telemetry of ocean data from buoys and ships was routinely attempted on the high-frequency (HF) bands. These bands, 3 to 30 MHz, are the traditional "shortwave" bands that have the capability of worldwide propagation, but the propagation is variable with time of day, season, sunspot cycle, and weather patterns. Consequently, one could never depend upon a transmission path being available between a given buoy and a given shore station. This problem was often overcome by sending the same information for long periods of time and hoping that it would get through now and then.

In addition, when the propagation path did exist between the buoy and the shore station, the arriving signal was often unintelligible due to interference or electrical noise or multipath interference. This problem was usually overcome by using slow data rates with redundant coding, and by the same repetitive transmissions used to overcome the propagation problems.

These two major disadvantages of HF telemetry, variable propagation and poor signal-to-noise levels, coupled with the growing availability of viable satellite channels, has caused HF telemetry to be almost unused today.

However, the satellite channels are not always available, and the ones most accessible to the ocean science community (ARGOS and GOES) have several disadvantages, including very low data rates (ARGOS), no good polar or eastern hemisphere coverage (GOES), complicated access to the data stream, and dependence upon satellites in the first place.

Data Rates

The most important characteristic that a modern HF telemetry channel could provide is an increased data rate over that provided by ARGOS or GOES.

ARGOS accepts 256 bits during each transmission, which are usually every minute. But the polar-orbiting satellite (NOAA/TIROS) that carries the ARGOS package is only in view for about 10 minutes perhaps 10 times per day, so the maximum data that can be sent up per day is about 256x10x10 or about 0.3 bps (bits per second) on average. This number is further reduced by the need to send the data redundantly because you never quite know which one-minute transmission is going to be heard by the satellite. At best then, the daily average throughput of ARGOS is about 0.1 bps.

GOES is usually used in its self-timed reporting mode, in which the platform transmits for about 30 seconds at 100 bps, thus giving 3000 bits per reporting period. There might be many of these per day but the absolute maximum data rate over a day would be 100 bps; 1-10 bps is a more likely data rate, depending on the platform duty cycle.

Typical Data Rates Needed

A simple drifter might want to transmit the surface temperature and barometric pressure once per hour; at 10 bits per variable, this is less than 0.01 bps daily average and is easily passed through ARGOS, which also provides the geographic position of the platform and so is the communications link of choice in this application.

A more complicated drifter might acquire the temperature from 10 subsurface points and also sample half a dozen surface meteorological parameters; 16 variables sent hourly pushes the data rate to about 0.05 bps so is approaching the limit of what can be sent easily through ARGOS.

There are schemes to get more than the 0.1 bps through ARGOS, but the schemes cannot be widely used because they all involve use of multiple ARGOS ID's; the schemes essentially make ARGOS think that it is dealing with, say, 4 different platforms when in fact it is dealing with one platform sharing 4 times the usual amount of data through 4 different ID's. These schemes may suffice for temporary small projects, but it produces saturation of the ARGOS system by a small number of users.

Given that ARGOS passes 0.1 bps on average, what kinds of projects might require 1, 10, or 100 bps? For reference, 1 bps is required by 50 12-bit variables sent every 10 minutes, all day long. A project that produces this much data might be a buoy with surface meteorological measurements of wind speed and direction, air and sea-surface temperature, relative humidity, barometric pressure, long and shortwave incoming solar radiation, temperature and current speed and direction from 12 depths beneath the surface, and 6 engineering parameters such as mooring line tension, battery and regulated voltage in each of two independent power supplies, and status of the flashing light on the buoy. Clever coding of the information can reduce the amount of data required (light status probably needs only one bit, for example), but redundancy to assure the data getting through will increase the number of bits.

10 bps might be required by a system that acquires surface wave data, and 100 bps would allow some acoustic data to be transmitted. The most likely of the higher data rate systems will be a moored or drifting doppler acoustic profiler: typically three variables (two current components plus scattering strength) of 12 bits each will be sent from each of 50 depth bins, every two minutes. This provides 15 bps, and will probably be supplemented by surface meteorology and other parameters. Clearly, 10-100 bps telemetry systems are needed in at least a few applications.

Can GOES do the Job?

Why not use GOES for these higher data rate needs? There are two main disadvantages to GOES, and some smaller ones. The biggest disadvantage is the coverage, which is not worldwide. The latitudinal extent is to about 70 degrees north and south, although orbital wobble permits a few hours each day

of its use even at the poles. The coverage is also only of the eastern Pacific and western Atlantic. A European satellite called METEOSAT, a Japanese satellite called GMS, and an Indian satellite called INSAT complete the worldwide coverage, but to use these requires separate agreements with each and separate schemes to get the data back from each. A second main disadvantage of GOES is the data stream: the usual means of getting one's data is to call the Central Data Distribution Facility in Maryland and get the data over the telephone wires. Another disadvantage is the data stream is one-way only, from platform to satellite. There are tremendous advantages to two-way transmissions, including control of the platform's functions and the chance to have hand-shaking data transmissions to insure data accuracy.

PACKET RADIO

Packet networks over telephone lines are familiar; Telenet is an example. The messages are broken into short segments that are sent along with error checking characters added (cyclic redundancy checks), and the receiving point checks to see if it received the data packet correctly. If so, it sends back an acknowledgment and waits for the next packet to be transmitted. If the packet was not received correctly, it is retransmitted until it gets through. Thus, packet networks are inherently two-way, and the amount of redundancy is increased as needed. The agreed protocol for typical packet networks is called X.25.

Amateur Packet Radio

Amateur radio operators have been experimenting for the last few years with a radio version of packet networks. Since a transmitted packet might be heard by many stations, a header is added to each packet to tell the various listeners which of them is supposed to error-check it and send the acknowledgment; this version of the packet network protocol is called AX.25.

Unlike telephone wires, which are as long as you need them, packet radio has a range limited by the frequency, power level, and antennas in use, and may also be affected by propagation paths. To extend the range of packet radio, AX.25 includes a store-and-forward capability called digipeating. The header on a packet can include specified repeater stations as well as the ultimate recipient for the packet. The repeater hears the packet and reads the header and finds out it is supposed to repeat it; this continues from repeater to repeater until finally the destination station hears the packet and sends its acknowledgment back along the reverse routing of repeaters to the originating station.

Packet radio is in daily use by more than 10,000 amateur radio operators in North America. The special equipment needed is a Terminal Node Controller (TNC) that has a serial RS232 connector on one end and a microphone connector on the other. A computer or terminal plugs into the serial connector and the microphone connector goes to a two-way radio. The TNC handles all the conversions of ASCII (from the computer) to modem tones, breaking messages into packets, adding error-checking characters, and error checking. The modem

sends two tones to the radio so that the transmissions are by AFSK modulation. The TNC acts in both directions so that only one is needed per station. Typical TNC costs are $200 and less.

It is also possible that two packets sent by stations that cannot hear each other collide at some point in their routing, thus destroying the information content of both. Each originating station will try again, but only after a random wait to avoid getting synchronized collisions. Of course, no TNC transmits if it hears the channel being used. The channels are thus time-shared to allow many users access to them. Data rates are traded off against multiple use in this way.

Much of the amateur packet radio is done on VHF bands, typically 144-148 MHz which is essentially line of sight, at rates of 1200 baud. The channel throughput is less than 1200 baud, however, because of the time for digipeating, acknowledgments, and retries of packets that had errors in them.

VHF ranges are 30-50 miles at most, and digipeaters are common. Since each TNC and associated radio is also a digipeater (it only has to read the header to decide if it should repeat what it just heard), everything is tightly linked into a Local Area Network (LAN). The trick is, how to link the LAN's so that broad area coverage can be achieved?

Two methods are under development: VHF/UHF trunk lines using very high data rates (i.e., 19.2 or 56 kbaud), and HF packet radio. The latter is of interest for ocean data telemetry.

HF Packet Radio

Essentially identical to the VHF packet networks described above, the only important differences are that data rates are necessarily less because of bandwidth restrictions in the HF bands, and the vagaries of HF propagation mean that the desired paths are not always present. Maximum amateur data rates on the HF bands are 300 baud in order to keep the bandwidths to less than 3 kHz. There is some amateur experimentation with adaptive modems that make initial contact at 50 baud or so and then increase the rates until the error rates are excessive; these Packet Adaptive Modems (PAM) are not yet operational.

The problem of variable propagation is unbeatable between two fixed points except by shifting frequencies to try and find one that has a workable path at the moment; this frequency agility complicates the installations at both ends and is not in common use.

Diversity Reception

Even though the transmission from a station on an HF band does not necessarily go where it is desired, due to the propagation for that band at that time at that place, it does go somewhere. Diversity reception means

having many stations listening for the transmission from the originating station; if one of them can hear the originator, then at least the message from the originator can be passed. This idea is in daily use by ships at sea: by choosing a frequency band and by not caring particularly which coastal station they are in contact with, they can at any moment expect to be able to connect in with the land-based telephone networks for the purposes of passing messages.

CONCEPTUAL HF PACKET NETWORK WITH DIVERSITY RECEPTION

Suppose a platform at sea is designed to store data on board until a certain limit is reached, and then to use HF packet radio to try and send that data ashore. It could send out a "connect request" on a specific frequency and try and reach its home laboratory, or it could be more open-minded and try and find anyone that can hear it and use that path. It could even shift frequencies if necessary until it finds a station that hears it.

Once it finds a frequency and path, it would dump its data at 300 baud using the standard AX.25 protocol until its buffer is empty, and then would disconnect and wait for its next need to transmit.

Ashore, the network of receiving stations would need to scan several frequencies and listen for connect requests, and be ready to accept data from the platform at sea. Once the shore station gets the data it would then need to send it to whomever wants it, presumably a laboratory somewhere but possibly to many sites. But many schemes are possible ashore, including telephone lines, satellite links, or even additional HF or VHF packet links.

It would be extremely inefficient to have to have a large number of shore stations for the diversity reception of a single platform at sea. But if many platforms needed shore receiving points, then the receiving effort is amortized. One platform at sea and one shore station can still use HF packet, and can even be frequency-agile, but in the end their daily data-rate totals will be affected by propagation problems.

Data Rate Estimates

What are the tradeoffs? How much data per day can be transmitted from one platform at sea on one frequency band, and how much more data can be transmitted by being frequency-agile, and by having diversity reception? We can state the upper limit as being 300 bps from a platform at sea, because this would assume 24-hour a day full use of the HF packet channel; any lost hours per day due to propagation or retries or lost bits would diminish this rate below 300 bps.

Again, amateur radio experience is helpful in making these estimates. One can expect at least a few hours each day of useful propagation from any point at sea to some point on land, especially if the frequency band can be selected and if north-south paths exist. The nature of HF propagation is that it is easier to propagate north-south than it is east-west, especially if the east-west path crosses the day-night boundary. Hence, the location of the

receiving stations is important as well as their number. Also, the lower frequency HF bands have less variable propagation from day to day and depend more upon diurnal cycles, but their ranges are shorter. This means that nearby receiving stations will have more hours per day of propagation to the platform at sea, on lower frequency bands. Again, the location of the shore stations is important; one would not want all their receiving stations in North America if the platforms were all in the Indian Ocean.

Some of these constraints could be relaxed if the shore station is made into a simple repeater that hears HF coming in and sends the signal on via geostationary satellite to a home station, where it is error-checked and acknowledged back through the "gateway" station via HF to the platform at sea. This could permit a number of diversity-receiving gateway stations ringing the ocean basin containing the platforms, with each of the stations linked back to the main station at home.

ASSESSING AN HF PACKET DATA TELEMETRY NETWORK

An orderly, learning approach to investigate the feasibility of the conceptual network described above would be to start with an assumed platform at sea transmitting a beacon that is listened for at a number of assumed receiving sites. The goal would be to estimate the duty cycle: how many hours per day can the beacon be heard, as a function of the location of the platform, the location and number of receiving stations, and the choice of frequency and equipment? This estimate can actually be made from available models of HF propagation: from a given point the number of hours of propagation per day to any other point can be calculated, as a function of frequency and sunspots, etc.

Next, a test of the value of the propagation model would have to be done, because the model is best at predicting the existence of the path and worst at predicting the quality of the path, but the quality is important at determining the number of retries, error rates, etc. The test would not have to be done from a platform at sea, but this would be the most useful in terms of demonstrating the value of the approach.

Finally, an assessment would be needed of the optimum number and location of receiving stations for a given distribution of platforms at sea, and a given data throughput needed.

Data Throughput Estimates

Amateur radio experience suggests that perhaps 2-3 hours per day of useful propagation ought to exist between any two points, if the frequency band can be selected. Assuming then that only 1/10 of the time a path exists, and that only 1/10 of the data can get through during the time the path is open, this still suggests that 300/10/10 or 3 bps can be passed through the link. Diversity reception must increase this rate.

It appears then that HF packet is capable of 1 to 2 orders of magnitude more data throughput than ARGOS, and may be comparable to or better than GOES. In addition, the link is inherently two-way and avoids all satellite links between the platform and shore. The disadvantage is the complexity of the diversity reception network and the distribution of received data ashore, but this is a one-time complexity that keeps the seagoing system as simple as possible.

HOW TO PROCEED?

Four things are needed: a demonstration of the validity of the concept, a study of the tradeoffs and estimates of the data throughput as a function of the network complexity, a design for the shore-based data distribution network, and an analysis of the costs of a system based on the concept. These are briefly described below.

Demonstration of the Concept

Firm information is needed on the reliability of HF packet radio connections over typical distances using typical equipment, and on the value of the simple propagation models for estimating the efficiency of a given path. If this information were available, then the models for link reliability and efficiency could be tested. One approach is to utilize amateur radio equipment, frequencies, and operators to obtain the information.

A ham could set up a demonstration HF packet radio on a research ship at sea, and other hams ashore could attempt to connect with him and to pass data, or at least messages. Alternately, the ham at sea could attempt connections with each of the shore stations. Which would be in control, the sea end or the shore end, is a question of the logistics and whether or not the roster of shore stations is known.

Whatever information is gathered from this field trial, it would then be modeled with the available propagation models. The next step (below) depends upon having a model that can be used to say "what if?" in the assessment of the tradeoffs between many receiving stations versus data throughput.

Tradeoff Study

Diversity reception is the key to eliminating the problems caused by HF propagation vagaries, but how much diversity provides how much data-throughput improvement? Using the validated propagation model, this question would be addressed.

Alternately, if the field test (above) had a large number of receiving stations participating, then the lessened data throughput of fewer stations could simply be simulated.

Once the optimum array of diversity receiving stations is established -- and this will be different for each platform location at sea -- the typical data throughputs can be established for typical platform locations. That is, only one receiving array ashore is reasonable, but which one provides the most benefits to each ocean basin, and to combinations of basins?

Network Design

Given the array of receiving stations determined above, the data distribution network must be designed to get the data back to the desired final destination. This may be some combination of telephone circuits or even satellite distribution circuits, but unless the data can get from the diversity receiving station to the final receiving station then the value of the scheme is lost.

A simple method to accomplish this is for each diversity station to periodically telephone the computer at the final destination and simply dump the data to a file. That computer would then have to unscramble the data because the sequence in which it arrives may be quite different from the sequence in which it was originally transmitted from the platform at sea.

Cost-Benefit Analysis

How much does it all cost? What is the cost to capitalize a simple system and a complex system with many diversity receiving stations and a rapid data dissemination network ashore? What is the cost per bit transmitted, and what is the energy requirement for the platform at sea?

For the simplest system, amateur radio again provides a guide as to some of the costs. It is approximately $600 for a fully synthesized 150 Watt HF transceiver, and $130 for the packet TNC. If the HF transceiver were 5 Watts and were designed for just the one frequency needed, then the cost of mass-produced CB radios of about $50 each sets the lower bound. An estimate of $300-400 per platform seems reasonable. Note that this is the only real cost, because unlike data telemetry by ARGOS there is no recurring cost per bit transmitted.

The shore station would be of comparable cost, plus a computer connected to buffer the incoming data and act as an interface to the data distribution network. The minimum computer and disc storage and printer adds to about $500 for a Commodore-64 system and a modem to call the results in; one could easily spend $4000 instead.

These costs need to be carefully assessed, but their trend is clear: a network of 20 diversity receiving stations could be assembled for under $20k, which is the cost of one Local User Terminal to gain access to the ARGOS data stream. The platforms at sea might be $400 each, which is less than half the cost of an ARGOS transmitter. Finally, the data rate through the HF packet system is some fraction of 300 bits per second; if the link is only one percent efficient then it still permits data rates that are 10-30 times higher than can be put through ARGOS.

The benefit of ARGOS is that it gives the position of the platform. For data transfer, the HF packet system has a very impressive potential.

HF FREQUENCY ALLOCATIONS FOR DATA TELEMETRY

The tests and experience described above are all on the amateur radio bands. Six HF frequency bands are internationally allocated for ocean data transmission under the Maritime Mobile Service; these would be available and appropriate for an operational HF packet network. The six bands, each of which is 3.5 kHz wide, start at 4162.5, 6244.5, 8328, 12479.5, 16636.5, and 22160.5 kHz. The bands were initially allocated twenty years ago and are channeled for 10 350 Hz slots within each 3.5 kHz band; a waiver would probably have to be obtained to permit use of the entire bandwidth for 300 baud ASCII transmissions.

APPENDIX I: WHOI TELEMETRY DISCUSSION, 3 JAN 86

Notes by M.G. Briscoe
5 January 1986

Mel Briscoe, Bob Beardsley, Jim Valdes, Bob Spindel, Bob Chase, and Ed Mellinger met in Clark 331 on 3 Jan 86 from about 0910 until 1000, to discuss common concerns and hopes about telemetry activities at WHOI in the context of the upcoming Telemetry Discussion to be held in New Orleans, 15 Jan 86, at the AGU/ASLO Ocean Sciences Meeting. Only Ed and Mel will be at the New Orleans meeting, with Jim still thinking about going.

In general, the attitude is tentatively aggressive: we are doing some things about data telemetry from buoys and drifters, we have some ideas about ships and possible futures, and we have more interests than time and people and funding to pursue them. But we also have some reservations about funding agency support and their own understanding of the needs and possibilities.

One hope expressed for New Orleans is to have the community make a clear statement of need, followed by a clear consensus on a limited number of directions in which to proceed. If the agency personnel present at the meeting can hear a clarion call rather than babel, and if a similar report is forthcoming from the meeting that can be pointed to and referenced in proposals, then we have a reasonable chance of getting on with the work. Otherwise, it is business as usual with ideas and proposals being deferred until "it is clear what the community wants."

What topics and approaches do we want to see on the New Orleans "consensus and priority" list?

1. **Ships of Opportunity** -- there is need for a standard meteorological package and low data-rate telemetry system that can be placed aboard a large number of ships, and operated satisfactorily for long periods of time without routine attention. At least one complete commercial package exists, including various telemetry options (Coastal Climate Corp.), and several "academic" meteorological packages using ARGOS. How well do these work? Which one (why just one?) should be settled on?

We could place one or more of these packages on the Oceanus, which is in port often enough to allow system checks, and run a long-term test and intercomparison. If other institutions have similar interests, then the work can be shared. Who to coordinate this within other labs? Who to pay for it?

There is also need for a nonstandard data telemetry system, that is, *ad hoc* transmittal of XBT or other sporadic sampling data. Even a doppler acoustic log with continuous medium data-rates might be on a ship of opportunity. Should the met package and its telemetry system be flexible enough to incorporate these other needs, or should the systems be separate, so as to keep the meteorological system as simple and reliable as possible?

Ship of Opportunity questions for New Orleans:

Who are the principal players in ship-of-opportunity observing systems and telemetry?

Who is interested in cooperating on a shipboard testing program of at least the Coastal Climate package (MICROMET)?

What are the needs for sporadic and medium or high data-rate telemetry systems from ships? Is this just from a few research ships or is it from a large number of volunteer ships?

2. **Drifting and Moored Buoys** -- low data-rate systems are handled well by System ARGOS, although the availability of the data is sometimes a problem...there are periods when the throughput is poor or zero, and there is always a many-hour delay. Local User Terminals can help in this regard.

Russ Davis's *In Situ* Ocean Science Working Group produced for NASA a report entitled "Satellite Data Relay and Platform Locating in Oceanography," dated November 1983. It was the opinion at our meeting that this report was optimistic when it was written, and at the least needs to be updated if not revised now, two years later. We recommend a "concerns" committee to make an independent and current judgment on this important issue.

There are also higher data-rate drifters, such as RELAYS and the Flux Buoys. The current scheme of data compression or multiple ID's so as to allow use of ARGOS is not something that can be pushed much further. Part of the historical constraint has been a need for platform location, and unwillingness to use GOES for data and ARGOS for position. But such a hybrid system may be necessary, which only adds the concern of whether GOES will do the job in the future as well as worrying about ARGOS.

GOES has sufficient data rate to allow a moored doppler profiler to send data ashore, but the coverage of GOES is not worldwide: it misses high latitudes and some oceans entirely. There are probably "black" satellites and "gray" satellites (like ATS-3 that oceanography uses now) that can easily do the job, but how to find out about them and get access?

GEOSTAR is a new positioning scheme that has considerable oceanic potential, if the GEOSTAR system is expanded to include additional satellites beyond their present plans. How do we find out if this is a worthwhile thing to push, and then how do we push it?

Buoy Questions for New Orleans:

Who can provide an update of the Davis document? Is this a fair project for the US-WOCE project office?

What are the communications satellites appropriate for our uses and how do we get access to them?

Who would like to cooperate in a test of the GEOSTAR system from a ship and from a buoy? Would Jim McCullough and his USGS navigational interests like to do or participate in this?

3. **General Telemetry Issues** -- Three other items were discussed. Clearly needed is a tradeoff study for oceanographic telemetry that considers data rates, energy per bit, antenna and power requirements, data pathways, transmitter cost and complexity, additional information available such as position, capital and operational costs, geographical constraints and coverage, and suitability for a few versus many platforms. This study is a moving target and so needs semiannual updates...perhaps the main conclusions could be on Telemail for ready updating and access. Several people at WHOI (Mellinger, Briscoe, Chase) are interested in participating in such a study.

There are many ongoing oceanographic telemetry projects in many labs in several countries; what are they? A survey of this activity could reveal useful trends (or redundancies!) and missing topics. At the very least, ONR and NSF-funded activities in the US should be summarized and reported.

Finally, the need for a clear statement by the oceanographic community for use by the community and the agencies is mandatory.

SUMMARY (with contributions from Ed Mellinger)

The paper study topics that we see as being of high priority are:

- ARGOS/GOES oceanographic potential, reexamination
- non-traditional satellites
- telemetry tradeoffs
- current projects
- future projects: data needs, technical possibilities

The hardware/field work projects that we see as being of high priority are:

- ship of opportunity telemetering meteorological packages
- GEOSTAR evaluation
- INMARSAT: equip the fleet in a coordinated way
- tests of "new" ideas such as HF packet or meteor-burst

Other topics of arguably lower priority are:

- ship of opportunity XBT and doppler log telemetry
- drifters of high data rate or low cost
- specific mooring needs, especially for subsurface moorings

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16. Abstract (Limit: 200 words)

This document contains two workshop reports and several brief technical reports, all on aspects of ocean data telemetry and platform positioning. The principal topic is a Summary of an Ocean Telemetry Workshop held at the AGU/ASLO Ocean Sciences Meeting in New Orleans, Louisiana, on 15 January 1986. A brief version of this summary appeared in **EOS, Transactions of the American Geophysical Union,** 4 March 1986. Both the full summary presented here and the brief form in EOS were coauthored by D. Brooks of Texas A&M University.

Included here is a list of the attendees at that workshop and a description of the goals and membership of the AGU Ocean Sciences Section Technical Committee on Ocean Data Telemetry and Platform Positioning, which was formed at that meeting. A report on an earlier, informal local workshop on telemetry held in Woods Hole in March 1985 is included. Technical summaries are given on Meteor-Burst Telemetry, the GEOSTAR positioning system, tradeoffs for various telemetry systems, a proposed communications network [authored by M. Comberiate from NASA Goddard), and the possibilities of a new kind of HF telemetry system. A small discussion at Woods Hole prior to the January Telemetry Workshop is reported.

17. Document Analysis a. Descriptors

1. telemetry
2. ocean data
3. meteor burst
4. HF Packet radio

b. Identifiers/Open-Ended Terms

1. AGU/ASLO Ocean Sciences Meeting workshops
2. D. Brooks
3. M. Comberiate

c. COSATI Field/Group

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